ST CROIX CORAL REEF SYSTEM

AREA OF PARTICULAR CONCERN (APC)

and

AREA OF PRESERVATION AND RESTORATION (APR)

A COMPREHENSIVE ANALYTIC STUDY

V.I. DEPARTMENT OF PLANNING AND NATURAL RESOURCES
Coastal Zone Management Program

September 21, 1993

Draft Prepared By:
Island Resources Foundation
under Contract PC PNR-330-92

With assistance From:
The University of the
Virgin Islands

This publication is financed in part through a federal grant from the Office of Coastal Zone Management, NOAA under the provision of Section 305 of the Coastal Zone Management Act of 1972 (Public Law 92-583).

Copies of this document may be obtained from the Department of Planning and Natural Resources, (Coastal Zone Management Program), Nisky Center, Charlotte Amalie, St. Thomas, United States Virgin Islands 00802.

ST. CROIX CORAL REEF SYSTEM
APC/APR *COMPREHENSIVE ANALYTIC STUDY*
TABLE OF CONTENTS

LIST OF KEY ACRONYMS

Area of Particular Concern	APC
Area of Preservation and Restoration	APR
Buck Island Reef National Monument	BIRNM
Coastal Barrier Resources System	CBRS
Coastal Zone Management Act	CZMA
Department of Housing, Parks, and Recreation	DHPR
Department of Planning and Natural Resources	DPNR
Department of Public Works	DPW
Division of Archaeology and Historic Preservation	DAHP
Division of Coastal Zone Management	DCZM
Division of Environmental Protection	DEP
Division of Fish and Wildlife	DFW
Federal Emergency Management Agency	FEMA
National Flood Insurance Program	NFIP
National Marine Fisheries Service	NMFS
National Park Service	NPS
Outstanding National Resource Waters	ONRW
Sea Level Rise	SLR
Significant Natural Area	SNA
Territorial Pollutant Discharge Elimination System	TPDES
U.S. Army Corps of Engineers	USACOE
U.S. Coast Guard	USCG
U.S. Environmental Protection Agency	USEPA
U.S. Fish and Wildlife Service	USFWS
U.S. Geological Survey	USGS
Water and Power Authority	WAPA

LIST OF FIGURES

1. INTRODUCTION

1.1 General

The St. Croix Coral Reef System is one of 18 Areas of Particular Concern (APC's) designated by the Planning Office in 1979 after public nominations and comment had been received (Figure 1). It consists of one of the best developed reef systems in the Caribbean and the most extensive coral reef system on the Puerto Rican-Virgin Islands shelf (Adey, *et al.*, 1981). The reef system is of great scientific interest for the variety of reef types and forms which it supports, and for the number of studies that have been carried out which provide invaluable baseline data for future monitoring and research. The reef system includes algal ridges, shallow and deep reefs, bank-barrier reefs, narrow fringing reefs, and patch reefs of various sizes, community structure, and composition. In addition to its scientific interest, the St. Croix Coral Reef System represents significant ecological, economic, aesthetic, and recreational values. In the Caribbean, about 180 of the approximately 350 known reef or reef-associated fish species have commercial importance, in addition to the spiny lobster *(Panulirus argus)* and conch *(Strombus gigas)* [Wells, 1988].

The Coral Reef System APC is comprised of the (three mile) territorial sea portion of an extensive insular platform which extends seaward for up to 15 km (9 mi) from Point Udall, the easternmost tip of St. Croix, including the Buck Island platform and a somewhat narrower platform along the southeast coast (Figures 2 and 3). Paralleling the shoreline, an almost continuous bank-barrier reef extends from Coakley Bay on the island's northeast side, around the East End and back along the southeast coast to the area of Great Pond Bay. An additional bank-barrier reef, Long Reef, protects Christiansted Harbor. Further west along the north coast, narrow and precipitously sloped fringing reefs are found at the mouth of Salt River Bay and along the coast from Cane Bay to Davis Beach. Other St. Croix reefs not within the APC include a patch reef system which extends west of the industrial area to Sandy Point, and a largely monotypic reef system along the coast from Frederiksted north to Sprat Hole (dominated by the mountainous star coral, *Montastrea annularis)* that has been adversely impacted by the anchorage of large vessels. Vertical relief on portions of this reef has been reduced to less than one-half meter (less than 2 feet) in height by anchor drag and chain swing.

Coral reefs are under increasing stress worldwide from a combination of natural and anthropogenic sources. Global climate warming, ozone depletion, and an increasing frequency and severity of hurricanes and El Nino Southern Oscillation (ENSO) events, are but a few of the changes currently underway which will likely place increasing stress on coral reefs around the world. Moreover, white-band and black-band disease, coral bleaching, and unexplained mass mortalities or population blooms of certain marine organisms known to play key roles in reef ecology are observable phenomena which Caribbean reefs have had to contend with during at least the past decade -- a decade of unprecedented levels of stress from multiple sources. While it is difficult in all cases to separate natural versus anthropogenic causes of these phenomena, a growing understanding of coral reef ecology has lead to considerable concern among scientists that man-induced changes to the marine environment are placing the health and productivity of coral reefs in an increasingly vulnerable position.

Sediment runoff from the terrestrial environment, other land-based sources of marine pollution such as sewage and industrial waste discharges, direct physical damage to corals from boat anchors or careless divers, and the overfishing of key reef species are again but a few of the many and growing number of man-induced stresses affecting coral reefs. And although the St. Croix Coral Reef System may appear to the first-time observer to be a picture of remarkable diversity and health, those who have known the same reef system for the past 20 years or more realize that significant degradation has already occurred and that serious, concerted actions are called for if further adverse effects are to be avoided.

On July 26th, 1991, the CZM Commission adopted the 18 APC's recommended in the Final Environmental Impact Statement (USDOC, 1979), which accompanies the Virgin Islands CZM Act. The Final Environmental Impact Statement notes "the importance of the entire coastal zone", but declares that "certain areas are of yet greater significance." It also establishes the criteria for the designation of Areas of Particular Concern which are as follows:

- Significant Natural Areas
- Culturally Important Areas
- Recreation Areas
- Prime Industrial and Commercial Areas
- Developed Areas
- Hazard Areas
- Mineral Resource Areas

In September of 1991, the Coastal Zone Management (CZM) Commission met and held public hearings on all three islands on the boundaries for all 18 APC's. The Commission met again on October 1, 1991 and, based upon public input and staff recommendations, approved the boundaries of the APC's.

APC management requires knowledge of an area's ecosystem dynamics, energy linkages, historical development, and traditional uses, and an action-oriented plan for the area's future utilization. This Comprehensive Analytic Study and proposed management plan is intended to serve as the overall planning and management framework within which the various regulatory entities carry out their respective decision-making duties under their authority.

The APC planning effort recognizes that permit decision-making is most often reactive; that is, the decision to approve or disapprove a proposed development is made in response to a permit request, not in advance of it. The general goal of developing an APC management framework is to be able to make *a priori* decisions about the allowable extent of modification of an entire landscape unit or marine ecosystem. In other words, to raise the level of decision-making from the site-specific to that of functional ecosystems and the maintenance of a wide array of interactive resource uses.

1.2 Relationship to Other Plans and Regulations

The St. Croix Coral Reef System APC Comprehensive Analytic Study and proposed management plan was prepared under the authority of the Coastal Zone Management Commission. The Study and proposed plan is intended to serve as the overall planning and management framework within which the various planning and regulatory entities carry out their respective authorities. It is intended that the policy framework contained herein be incorporated into the policies and review criteria of those entities, including, but not limited to, the Department of Planning and Natural Resources (DPNR), the Department of Housing, Parks and Recreation (DHPR), the Port Authority, the Water and Power Authority (WAPA), the Department of Public Works (DPW), the National Park Service (NPS), the U.S. Fish and Wildlife Service (USFWS), the U.S. Army Corps of Engineers (USACOE), the U.S. Environmental Protection Agency (USEPA), and the Department of Property and Procurement. This Study and proposed plan will serve as a guide for future decisions concerning the area. Future development activity should be consistent with the Study and proposed management plan.

The intent of this Study is for all participating territorial and federal agencies to utilize the broad policy framework to guide planning and permit decisions with respect to their own authorities. For those agencies that issue permits or review and comment on permit applications, the Study and management plan does not eliminate the authority of those agencies, but increases the predictability and timeliness of the permitting process since many of the issues that must be addressed in a specific permit application are already addressed and mandated in the Plan.

The issues surrounding any proposed use or activity within the coastal environment are complex. A proposed use immediately outside the boundary of the APC planning area may result in significant adverse impacts on the APC and impair the goals of the APC management framework described herein. This Plan contains several different forms of guidance, all of which should be considered in evaluating impact on an APC. Both the individual property owner who is considering a specific proposal and the decision-maker who is evaluating the proposal should follow the guidance of this Plan.

1.3 Other Classifications

Several of the "other classifications" discussed below do not fall directly within the APC boundary, which does not extend inward (landward) from the shoreline. These other classifications are included, nevertheless, for their intrinsic values, and potential overlapping management objectives with those of the APC.

With the adoption of the CZM Program, several sites within or adjacent to the St. Croix Coral Reef System were identified as potential Significant Natural Areas (SNA), including the following (Teytaud, 1980a):

1. Ham's Bluff/Davis Bay scarps;
2. Rust-op-twist mangroves/littoral forest;
3. Salt River Bay complex;
4. Long Reef;
5. Protestant Cay;
6. Altona Lagoon;
7. Punnett Bay Beach;
8. Southgate Pond/Chenay Beach;
9. Green Cay;
10. Prune Bay Beach;
11. Coakley Bay Pond and beach;

12. Buck Island and reefs;
13. East End;
14. Mt. Fancy Salt Pond;
15. Great Pond; and
16. St. Croix Barrier Reefs.

The Coastal Zone Management Act (CZMA) makes frequent reference to SNA's which it defines as "... land and/or water areas within the coastal zone of major environmental value, including fish or wildlife habitat areas, valuable biological or natural productivity areas, and unique or fragile coastal ecological units or ecosystems which require special treatment and protection." The territorial CZM Program further elaborates the concept by adding the categories of:

1. natural areas that provide scientific and educational value;
2. areas necessary for nesting, spawning, rearing of young, or resting during migration; and
3. areas needed to protect, maintain, or replenish coastal lands and resources (Teytaud, 1980a).

An effort to survey and describe the biological attributes of SNA's was initiated in 1989 by DPNR/DCZM. However, the project was terminated prior to completion, and as of yet no official designation of SNA sites has occurred.

Five sites adjacent to the Coral Reef System are nominated as Areas of Particular Concern. A Comprehensive Analytic Study and proposed management plan has been prepared for each of these areas, which include:

1. Salt River Bay and Watershed;
2. Christiansted Waterfront;
3. Southgate Pond/Chenay Bay;
4. East End; and
5. Great Pond and Great Pond Bay.

Several sites within or adjacent to the APC are included in the Federal Coastal Barrier Resources System (CBRS), including:

1. Rust-op-twist;
2. Salt River Bay;
3. Altona Lagoon;
4. Southgate Pond;
5. Coakley Bay;
6. Robin Bay; and
7. Great Pond Bay.

The Federal Coastal Barrier Improvement Act of 1990 established these areas in the USVI as part of the CBRS. The purpose of the system is threefold (Island Resources Foundation, 1986):

1. To halt development in low-lying areas subject to natural disasters (i.e., flooding, hurricanes, etc.);
2. To stop wasteful federal expenditures in these areas; and
3. To protect valuable natural resources from being destroyed by unwise economic development.

By law, federal expenditures (e.g., grants, loans, federally backed insurance, etc.), including federal flood insurance, are prohibited for development projects within a designated CBRS site. The law does not, however, prevent projects from moving forward with private backing. Certain exemptions are allowable for park lands, recreational areas, public recreation infrastructure, and land acquisition.

Buck Island, located 2 km north of Tague Bay, and its adjacent reef system were established as the Buck Island Reef National Monument (BIRNM) in 1961. The monument is comprised of 356 hectares, 80 percent of which is marine. Under the jurisdiction of the National Park Service, the BIRNM has been the focus of numerous research efforts and long-term monitoring studies. Gladfelter, *et al.* (1991) and Gladfelter (1992) provide the most complete listings of the studies and reports completed to date of this ecologically, economically, and scientifically important reef area.

Another fragile environment within the boundaries of the APC/APR is the Green Cay National Wildlife Refuge, designated in 1977 to protect the rare and endangered St. Croix Ground Lizard *(Ameiva polops)*. Green Cay has been established as critical habitat for the St. Croix ground lizard Ameiva polops under the Endangered Species Act by U.S. Fish and Wildlife Service. Green Cay and its offshore seagrass beds and fringing reefs provide habitat for many terrestrial and aquatic species including nesting sea turtles. The birds found on Green Cay include many federally and locally listed endangered species that use Southgate Pond for feeding, roosting, and nesting.

Approximately 139 km^2 (54 mi^2) of territorial and federal waters on the island's East End were proposed as a National Marine Sanctuary in the early 1980's (Figure 4). The proposed site included the waters around Green Cay and Buck Island, and the area of Lang Bank out to the 18 m depth. Several features of the area were identified as rationale for consideration as a Marine Sanctuary, including the following (Chelsea International Corporation, 1983):

1. A rich diversity of tropical marine organisms depend upon the maintained integrity of the site;
2. Lang Bank is identified (by DPNR/DCZM) as a Critical Area of high biological productivity;
3. The area is an important field research site for scientific investigation of tropical marine habitats and offers great potential as an interpretive center; and
4. The area supports a small artisanal fishery.

Finally, and although no designations have yet been made, it is planned that several sites within the APC will be nominated for inclusion in the territorial Marine Reserve System. The general purpose of the Marine Reserve System is to relieve pressure from human activities on critical marine sites. Twenty-three sites on St. Thomas and St. John have been selected following public hearings. The present status of the Marine Reserve System is on-hold, pending completion of the identification of proposed sites for St. Croix. Governor Farrelly has expressed his desire to take action on a completed package of proposed territory-wide sites.

2. DESCRIPTION OF THE SITE

2.1 APC Boundary

The boundary for the St. Croix Coral Reef System APC, established by the Coastal Zone Management Commission, is described as follows (Figure 2):

> Beginning at a point on the shoreline four hundred (400) feet west of the western end of Davis Beach; then north to the outer shelf edge or three mile limit (whichever is closer); then east following the shelf edge or three mile limit to and around Point Udall (including Buck Island); continuing southwesterly along the shelf edge or three mile limit to a point due south of Milord Point, then due north to Milord Point; and then, initially heading easterly, the boundary extends along the shoreline back to the western end of Davis Beach, the point of origin.

2.2 Ownership Summary

With the exception of the federally owned Buck Island Reef National Monument and the Green Cay National Wildlife Refuge, all areas within the APC are (submerged and tidally influenced) public trust lands under the jurisdiction of the USVI Government.

2.3 Physical Environment

2.3.1 Climate

Rainfall in the Virgin Islands generally increases with increasing elevation and exhibits a trend on each island of a dry-to-wet cline from the east-to-west. Average rainfall data, compiled from several years of records at various stations can be misleading in that it probably poorly represents the available precipitation at a particular area in any given year. The U.S. Virgin Islands receive an average of 41 inches of rain per year (Bowden, 1968).

The wettest months are September to December, and the dry season is February to July. Most of St. Croix receives 35-45 (average about 40) inches of rainfall per year. The northeast hills receive slightly more, and Annaly, the wettest area, receives an average of 52 inches per year (Bowden, 1970). Rainfall usually occurs in brief, intense showers of less than a few tenths of an inch. Downpours of up to several inches in a 24-hour period are, however, not uncommon.

Temperatures average an annual 79 degrees Fahrenheit, with the winter low averaging 76 degrees F and the summer high reaching an average of 84 degrees F.

The Virgin Islands lie in the "easterlies" or "trade winds" which traverse the southern part of the "Bermuda" high pressure area; predominant winds are thus from the east-northeast and east (Island

Resources Foundation, 1977). Trade winds average about 15 to 20 knots and vary seasonally, but most significantly during the late summer months when tropical depressions may form resulting in storms and/or hurricanes. Hurricane season is from June to November, with peak activity occurring in September. The annual probability of a hurricane is once every 16 years (Bowden, 1974).

2.3.2 Geological Setting

St. Croix was formed from volcaniclastic sediments deposited in ocean depths during the Upper Cretaceous period approximately 80 million years ago. The elevated eastern and western sections of the island are comprised of Upper Cretaceous rocks separated by recessed Miocene limestone (Whetten, 1974). The eastern slopes of the island are composed largely of shallow gravelly clay loams of the Cramer series, as well as Descalabrado series clay loams. Both of these soil types erode easily (USDA, 1970). Jaucas series sands are found along the coast, and are composed principally of mollusks and the carbonate-producing marine alga, *Halimeda,* which are the predominant contributors to the production of marine sediments (pers. comm., D. Hubbard, Marine Geologist). Red sand grains abundant on some on beaches in the APC, for example Jacks Bay, are derived from the red skeleton of the carbonate producing protozoan, *Homotrema rubrum,* which grows in shallow water often on the underside of large pieces of coral rubble.

The earliest St. Croix reefs likely originated during the Pleistocene period approximately 125,000 years ago while the sea level was near its present position (Hubbard, 1991). Pleistocene reefs occurred on the Cretaceous bench and developing carbonate platform. Subsequent to the formation of the early reefs, sea level dropped by as much as 100 meters below present level (due to global cooling and glaciation), exposing the insular shelf. Subsequently, the carbonate platform underwent erosion due to aerial and dissolutional forces of rainwater (Hubbard, 1991).

During the Holocene period (approximately 7,000 years B.P.), rising sea level flooded the insular shelf of the Virgin Islands. Eventually, Holocene reefs became established on preexisting marine features of the Pleistocene platform and Cretaceous bench. Coral reef carbonate structures emerged on sediment accumulations along the shelf (MacIntyre, 1988). Some present-day St. Croix reef structures are only approximately 5000 to 6000 years old (MacIntyre, 1988).

The history of reef development may provide a useful framework for assessment of present-day reef structures. For further details regarding the geologic development of St. Croix's reefs, refer to MacIntyre (1988), Hubbard (1989a), or Hubbard (1991).

Historical seismicity in the USVI

As a result of convergence between the Caribbean and North American tectonic plates, the Virgin Islands are located in one of the most earthquake prone regions of the world. During the past 450 years, damage has occurred from earthquakes and associated tsunamis. Strong seismic shocks were recorded for the Virgin Islands in 1777, 1843, 1867, and 1918. Destructive tsunamis occurred in the U.S. Virgin Islands in 1867 and in 1918; the latter resulted in 116 deaths and economic losses estimated at $4 million (in 1918 dollars) [USGS, 1984]. The 1867 tsunami was reported to have a wave height of 27-feet above sea level (Geoscience Associates, 1984b).

Potential human and economic losses for a similar event occurring today would be several orders of magnitude higher. Scientists report high seismic potential for a major fault rupture in the Puerto Rico Trench north of Puerto Rico and the Virgin Islands (USGS, 1984). The Virgin Islands are classified as "Zone 4" for earthquake vulnerability, the highest damage zone and the same classification given to many parts of California (Brower and Beatley, 1988).

Studies prepared in 1984 estimated that an earthquake of MMVIII intensity (the Modified Mercalli Scale, used prior to the Richter Scale) has a recurrence period of between 110 and 200 years for the St. Thomas/St. John area. The probability of such an earthquake occurring in the next twenty years is between 50 and 70 percent, and between 60 and 80 percent during the next 50 years (Geoscience Associates, 1984a and 1984b). It is not clear whether the same probabilities can be assigned to St. Croix, as the island is situated on a different shelf platform than St. Thomas and St. John. Chelsea International Corporation (1983) notes that the East End/Lang Bank region experiences "shallow-focus seismic activity, and that tsunami waves have been noted historically along these shores".

2.3.3 Hydrological Setting

With roughly one-half of St. Croix's shoreline included within the APC, total sediment and pollutant contributions from terrestrial runoff are significant. There are approximately 60 watersheds which discharge into the APC. The 12 largest watersheds for which total acreage has been calculated by BC&E/CH_2M Hill (1979), comprise approximately 7,750 acres (Figures 5a-d).

Many of these watersheds have been modified by development for residential and commercial purposes, increasing natural stormwater runoff rates and decreasing natural groundwater storage capacity. Areas which remain well vegetated retain or slow stormwater runoff, whereas areas denuded of vegetation or replaced with non-permeable surface materials (e.g., paving, concrete, etc.) prevent percolation and increase the volume and rate of runoff.

2.3.4 Oceanographic Setting

Oceanographic currents in the vicinity of St. Croix are westward flowing, and generally in the range of 0.5 to 1.1 knots (Hubbard, 1989b). However, frequent current shifts to the east occur. Waves approach the island from the east approximately 60 percent of the time. Occasionally, long period swells from the North Atlantic reach northern and eastern shores during winter months, sometimes passing unimpeded through the Anegada Passage. These swells break in depths of 10 m or more on the shelf edge (Adey, *et al.*, 1977). Otherwise, long-period swells approaching from the east-southeast, with wave heights less than one-foot, are the norm (Hubbard, 1989b). Tides are mostly diurnal, with a mean range of 0.8-1.3 feet (O.24-0.40 m) [Island Resources Foundation, 1977]. Sea temperatures range from 26.0-29.5°C, as measured at Buck Island (Gladfelter, *et al.*, 1977).

A period of frequent tropical depressions occurs in late summer (peaking in August and September), during which tropical storms and hurricanes commonly form. The majority of hurricanes pass the island without making landfall, but even when they do, freshwater and sediment runoff, together with wave action, can cause considerable damage to the reef system. Hurricanes have either struck St. Croix or passed close enough to impart reef damage at least six times during the past 15 years.

2.4 Biological Environment

2.4.1 Associated ecosystems

As the name implies, the St. Croix Coral Reef *System* is comprised of numerous biological communities, many of which share as their common substrate the stony, skeletal framework known as the coral "reef". Thus, in addition to the coral polyps, which form colonies that comprise what is known as living coral, the reef system is in fact an entire benthic (i.e., bottom dwelling) community comprised of numerous kinds of plants and animals. These include the hard, reef-building corals (principally of the Orders Scleractinia and Hydrocorallina), the soft corals (gorgonians), coralline algae, sponges, tunicates, sea anemones, zoanthids, and even motile organisms such as echinoderms (starfish, sea urchins, etc.), mollusks, crustaceans (lobster, crabs, shrimp), fishes, and sea turtles.

Many of these reef organisms are dependent, for at least a portion of their life cycles, on associated marine ecosystems, especially mangroves and seagrass beds. Although much is now known about the interactions between these ecosystems, their less obvious biological interdependencies are not fully understood. The following brief discussion is intended to provide only a broad basis for understanding some of these interactions, especially as they may relate to reef system management.

<u>Coral Reefs</u>

Coral reefs are submerged limestone ridges (or clusters) hosting a diverse shallow marine community of organisms. They are among the most complex and biologically diverse ecosystems, and are often compared with tropical rainforests for the numbers of species they support. Reefs are highly productive areas in otherwise mostly barren, tropical waters which generally exhibit low levels of dissolved inorganic nutrients (Birkeland, 1990). This paradox is explained by the fact that most of the nutrients in the reef system are bound up in the biomass, and are efficiently recycled by a variety of microbiological, physiological, ecological, and physical (i.e., hydrodynamic) processes.

The predominant species found on most reefs are long lived. Longevity and low rates of turnover promote a strategy of continual growth and large size of individuals (Birkeland, 1990). Thus, three factors make oceanic island coral reefs especially vulnerable to overexploitation: (1) the majority of nutrients are accumulated and in effect "stored" in the standing stock of biomass; (2) large size individuals generally prevail (thus, fewer individuals contain a higher percentage of total biomass); and (3) the system must generally rely on outside sources to replace lost nutrients.

The benthic environment of the coral reef ecosystem is dominated by corals and calcareous algae (also known as coralline or crustose algae). Calcium carbonate materials secreted by the "true" (or hermatypic) corals, along with calcareous algae, provide the foundation for reef structure. As carbonate materials from each successive live coral colony accumulate and become cemented into the reef foundation, a reef structure is built. In addition, and under certain conditions, several genera of red (calcareous) algae often grow as calcified encrustations and form what are called "algal ridges" on top of the reef framework.

In addition to the "true" or hermatypic, reef-building corals, some coral species exist in deeper, colder waters and in dark areas on reefs such as caves. These ahermatypic species do not have a symbiotic relationship with photosynthetic algae as do the true corals (see below) and usually do not form reefs.

The major reef-building organisms of St. Croix include the *Acropora* spp., *Montastrea* spp., *Diploria* spp., and *Millepora* spp. (fire corals) corals, and the shallow water coralline algae. Together, these are capable of reef-building growth rates of over 6-10 meters per thousand years "under the right sea level and antecedent platform conditions" (Adey, *et al.*, 1977). Other types of corals, however, have growth rates as low as 0.38 m per thousand years (Davies, 1983 as reported in Wells, 1988). For a good introduction to the classification of St. Croix corals, see Suchanek (1989).

Corals are colonial, sessile (i.e., attached to a submerged surface) marine animals. A coral colony is comprised of individual coral animals (called polyps) that have a single gastrovascular cavity, mouth and tentacles, and produce an external carbonate skeleton which forms the coral head. Polyps are predatory and feed at night on zooplankton in the water column by extending tentacles with stinging nematocysts. Although the coral polyps are predators, they cannot obtain enough nutrients from the water column and have thus evolved a symbiotic relationship with microscopic, yellow-brown algae, called zooxanthellae, which process the polyps' waste products and retain valuable nutrients (LaPointe, 1989).

The zooxanthellae use nitrogen wastes and carbon dioxide from coral respiration for photosynthesis. In return, the symbiotic algae produces oxygen and food that is taken up by the coral polyp. The algae also assists in removing carbon dioxide. One important result of this symbiosis, is that reduced carbon dioxide concentrations stimulate coral skeleton production. This mutualism is an efficient adaptation for survival of both organisms in tropical waters which, as mentioned above, have generally low ambient nutrient levels and low rates of primary productivity from phytoplankton (Birkeland, 1990).

Macroalgae (or benthic algae) compete with corals for substrate space, and are kept in balance by grazing, herbivorous organisms, including reef fishes (especially parrotfish and tangs) and sea urchins such as the long-spined sea urchin, *Diadema antillarum*. Any disruption to this grazing balance (through overfishing of grazers or other alterations of the natural system) can result in the prolific growth of macroalgae and the demise of live coral.

Following the experimental removal of thousands of long-spined sea urchins from a Tague Bay Reef in the mid-1970's, rapid changes in the structure of plant communities resulted (Ogden, 1976). In 1983, the long-spined sea urchin succumbed throughout the Caribbean to an as yet unidentified water-borne pathogen, resulting in the dramatic growth of macroalgae and changes to reef structure throughout the region, including the St. Croix reef system (Lessios, *et al.*, 1984; Williams and Williams, 1987). The long-spined sea urchin populations on St. Croix reefs have somewhat recovered, but remain below their pre-1983 levels (pers. comm., E.H. Gladfelter, Marine Biologist).

Corals are classified according to their general morphology and fall into two classes: (1) Class Anthozoa, the true or scleractinian corals and (2) Class Hydrozoa, the hydrocorals or fire corals. Class Anthozoa includes the soft and hard (or stony) corals. Soft corals (primarily represented by the gorgonians in the Caribbean) have carbonate needles aligned within intricate branches and/or a horny stem surrounded by soft tissue. Gorgonians demonstrate a variety of morphologies, but commonly occur as fans, bushes and branching whips of vivid colors. Hard corals, on the other hand, produce a stony structure. Hard corals also demonstrate a variety of morphologies, most common of which are the platy, branching, spherical, and encrusting forms. As mentioned, Class Hydrozoa includes the hydrocorals, of which the various "fire corals" are well known.

Approximately 60 species of stony corals are found in the Western Atlantic region. Of these, three species of hydrocorals (Class Hydrozoa) and thirty-four species of scleractinian corals (Class Anthozoa), comprise the thirty-seven species of reef-building corals most common within the St. Croix Coral Reef System (Suchanek, 1989). Common reef-building corals which dominate the APC include the following (Adey, *et al.*, 1977; Suchanek, 1989):

Acropora cervicornis (staghorn coral);
Acropora palmata (elkhorn coral);
Acropora prolifera (fused staghorn coral);
Diploria clivosa (knobby brain coral);
Diploria labyrinthiformis (grooved brain coral);
Diploria strigosa (smooth brain coral);
Montastrea annularis (mountainous star coral);
Montastrea cavernosa (cavernous star coral);
Meandrina meandrites (butterprint brain coral);
Agaricia agaricites (leaf coral);
Agaricia lamarcki (sheet coral);
Porites astreoides (mustard coral);
Porites furcata (finger coral);
Porites (club finger coral);
Siderastrea radians (rough starlet coral);
Siderastrea siderea (smooth starlet coral);
Millepora alcicornis (encrusting fire coral);
Millepora complanata (leafy fire coral); and
Millepora squarrosa (square fire coral).

Calcareous (or coralline or crustose) algae is the second major reef-building community. Coralline algae add to the accretion of calcium carbonate by growing as calcified encrustations on the shallower, mostly seaward portions of the reef. These encrustations build to become distinct prominences called algal ridges. Coralline algae are plants that secrete large amounts of calcium carbonate. They thrive under the high light intensities of the shallowest waters.

In shallow turbulent areas (such as on the seaward or fore reef portion of the reef), coralline algae can be the dominant reef-building community and can form ridges as much as 15 m wide. Good examples of algal ridges can be found within the APC on the island's southeastern reef system; they are described by Adey (1975) [Figure 6]. Here, because of their tolerance of high wave-energy conditions, the calcareous algae find little competition for space.

As a general characterization of the St. Croix reef system, algal ridges prevail in high-energy areas, elkhorn coral predominates in slightly lower wave energy areas, and staghorn coral predominates in more protected settings (Hubbard, 1989b). Coral rubble from storm damaged elkhorn communities provide good substrate for coralline algae, which thrive in the high wave-energy environment where herbivorous fishes such as *Sparisoma rubripinne,* the Redfin parrotfish, can feed only when seas are calm.

Other significant producers of calcium carbonate include the mollusks (shells), sponges, and foraminiferan protozoans. Sponges are sessile (bottom dwelling) filter feeders producing carbonate needles as support for chambers within the organism. Foraminiferans are microscopic marine organisms which reside in a carbonate shell or "test". The most obvious foram on Caribbean reefs, *Homotrema rubrum,* is bright red and grows primarily on the underside of coral rubble in shallow water. Carbonate sediments from both types of communities are incorporated into the reef structure.

Reefs are host to a wide array of marine organisms. The variety of microhabitats within and surrounding reefs encourages high biological diversity. Anemones, jellyfishes, sponges, snails, clams, squids, octopods, chiton, shrimp, crabs, lobsters, barnacles, sea stars, sea urchins, brittle stars, sea cucumbers, bryozoans, worms, reef fishes, pelagic fishes, turtles, rays, segmented worms, plankton, foraminifera and other protistas are among the many groups of organisms represented in the reef ecosystem.

Seagrass Beds

Seagrass beds often occur in close association with coral reefs in shallow marine waters. The term "seagrass" refers to some 60 species worldwide of flowering plants that colonize the sea. They are vascular plants (i.e., nutrients flow between their roots and stems) and have a root-rhizome system. The presence of roots and a vascular system, and their ability to flower, distinguishes seagrasses from the algae or seaweeds. Within the APC, four predominant genera are found: *Thalassia, Syringodium, Halodule,* and *Halophila.*

Seagrasses can occur in shallow water to depths of up to 20-25 m as uniform meadows or small grass patches. They support a wide variety of marine organisms, including invertebrates, such as the queen conch, sea urchins, and nudibranchs; fishes, such as parrotfish and surgeonfish; and green sea turtles. Some reef fishes find shelter in coral reefs during the day and move to seagrass beds at night to feed, including grunts *(Pomadasyidae)*, snappers *(Lutjanidae)*, and squirrelfish *(Holocentridae)*. In addition, seagrass beds serve as nurseries for certain reef fishes, including spiny puffer *(Diodon* spp.), yellowtail snapper *(Ocyurus chrysurus)*, yellow goatfish *(Mulloidichthys martinicus)*, all three Atlantic species of surgeonfish *(Acanthurus* spp.), and numerous wrasses *(Halichoeres* spp.) [Ogden and Zieman, 1977].

Seagrass beds provide a number of ecological functions, and are characterized by (adapted from Fonseca, 1987):

1. a high rate of leaf growth;
2. large numbers of epiphytic organisms on leaf blades;

3. epiphytic organisms which are grazed extensively and may be of comparable biomass to the leaves themselves;
4. leaves which produce large quantities of organic material, which decomposes on-site or is exported;
5. few direct consumers, while detritus forms the base of a complex food web;
6. an ability to reduce benthic currents and enhance substrate development;
7. the presence of roots, which by binding sediments, stablize sediments reducing erosion and preserve sediment microflora; and
8. an ability to influence nutrient cycling across the sediment-water column interface.

In summary, the high biomass, productivity, and turnover rate of plant material in seagrass beds supports a diverse community of detritus feeders which serve to re-incorporate decaying organic matter into the trophic system (McRoy, 1983). Moreover, the contribution of seagrass beds to removing sediment from the water column is of critical importance to the health of live coral (section 2.4.4) Finally, seagrass beds serve to dissipate wave energy and are thus an important component to overall coastal hydrodynamics and for shoreline protection.

Seagrass beds are utilized by a variety of herbivorous organisms including fish, conch, sea urchins, etc., and by predators feeding on invertebrate fauna living in the beds (Ogden and Zieman, 1977). Seagrass blades do not offer good refuge (shelter) for any but the smaller fish, and so mid-range sized fish are often excluded from foraging on seagrass beds (away from the protective reef where they are vulnerable to predation). Where a seagrass bed is juxtaposed to a coral reef, there is often a zone (10-15 m wide) where no seagrass grows. Evidence suggests that the "halo", as this area of open sand or heavily grazed seagrass is called, is the result of a combination of nocturnal feeding forays by reef fishes and sea urchins *(Diadema antillarum)*, and benthic currents which work to undermine coral reefs (Ogden and Zieman, 1977). For more on halo formation, see Ogden, *et al.* (1973).

Most inshore bay bottoms and back reef lagoons are covered with seagrass beds, as are some extensive areas on the shelf. The distribution of seagrass beds is determined by a number of factors, including sediment type and stability, depth, water clarity (turbidity), grazing by herbivorous organisms, and nutrient concentrations. Their growth is interrupted in channels or other areas of swift currents, or in surge areas with continual sediment suspension. In very turbid situations, the depth to which seagrasses can grow becomes so shallow that they are often destroyed by exposure at low tides (Fonseca, 1987). Significant seagrass beds within the St. Croix Coral Reef APC are located at Salt River Bay, Tague Bay, Buck Island Channel, and embayments along the southeastern reef system.

<u>Mangroves</u>

Coastal mangrove ecosystems form a close association with coral reefs and seagrass beds. Red mangroves (*Rhizophora mangle*), Black mangroves (*Avicennia germinans*), and White mangroves (*Laguncularia racemosa*) are found along the shoreline of several embayments within the APC, providing food, substrate, or refuge for a wide variety of terrestrial and marine organisms. Mangroves contribute organic matter and nutrients, and serve to filter and trap sediments and nutrients which are introduced into the marine environment *via* tidal flushing, wave and current action, and stream flow. They are thus, like seagrass beds, instrumental in reducing the amount of suspended particulates in the water column.

Mangroves are a critical component of the reef system nutrient cycle. Leaf litter from mangroves provides nutrients for detritus feeders, bacteria, and plankton. Their prop roots provide nursery habitat for a variety of commercially and recreationally important fishes and invertebrates, including pelagic and reef fishes, lobsters, crabs, and oysters. Both adult and juvenile fishes commonly occur among the mangrove prop roots. Some birds and reptiles spend part of their life in mangrove lagoons or may regularly visit the mangroves for food.

Unfortunately, over 50 percent of the mangroves of St. Croix have been destroyed through human development within the past 200 years. Remaining mangrove stands within or adjacent to the APC are located at Rust-op-twist, Salt River Bay, Altona Lagoon, Southgate Pond, and Great Pond Bay. The most extensive mangrove stands exist at Salt River Bay.

2.4.2 Reef types, zones, and distribution

Numerous studies have variously described the fauna and flora of the St. Croix Coral Reef System. This section is intended only to provide a sketch of the biological resources as synthesized from several sources, including the following: Adey, *et al.*, 1977; Gladfelter, *et al.*, 1977; Adey, *et al.*, 1981; Anderson, *et al.*, 1986; and Hubbard (ed.), 1989a. Prior to a description of biota occurring within the APC, however, it is relevant to elaborate on the general reef types found on St. Croix (Figures 5a-d) as presented by Adey and Adey (1979). [Note: Adey and Adey's detailed mapping of the reef zones (Figures 5a-d) is the most comprehensive reef mapping effort to date for the island of St. Croix. They based their work on a set of high quality aerial photographs taken by National Ocean Survey between 1971 and 1977.]

Reefs are generally ascribed to categories based on general characteristics and their location in relationship to the shoreline. Bank-barrier reefs are submerged limestone ridges located offshore on the insular shelf. They run parallel to the shoreline, creating a shallow channel or lagoon between the reef and shore. Fringing reefs are submerged limestone ridges contiguous with the shoreline. Patch reefs exist as isolated coral aggregations in regions between developed reefs or in back reef lagoons.

Differences in the abundance and distribution of reef organisms within a reef conform to general patterns or zones, including the following: mixed corals, shallow fore reef, deep reef, pavement, and algal ridge. These zones are differentiated by local topography (i.e. location on the reef) and differences in dominant benthic biota.

The mixed coral zone occurs in waters of less than fifteen feet depth. This zone comprises a shallow reef flat behind the reef crest, and is typified by scattered patch reefs, fringing reefs, and lagoons. Reduced wave action and high light intensity are important determinants of community structure in this zone. Common constituents of the mixed coral zone include elkhorn coral (*Acropora palmata*), the finger corals (*Porites spp.*), and the head corals (*Diploria* spp. and *Montastrea annularis*).

The shallow fore reef zone is located higher on the carbonate ridge than the deep reef zone. This zone extends from the reef crest down to twenty feet (or as much as 40 feet in clear water). Within this zone occurs the greatest coral and coralline algae growth on the reef. Abundance and distribution of reef-building organisms are influenced by high sunlight intensity, high degree of wave action, and shallow water depth. Dominant constituents of this zone include the elkhorn coral (*Acropora palmata*), fire coral (*Millepora* spp.), the purple sea fan, and coralline algae.

The deep reef zone occurs in waters twenty to seventy feet in depth, but in some cases up to 200 feet in depth. Common organisms of this zone include head corals (*Montastrea* spp., and *Diploria* spp.), platy corals (*Mycetophyllia* spp. and *Agaricia* spp.), staghorn coral (*Acropora cervicornis*), sponges, sea whips, and sea fans (gorgonians). Regions described by the deep reef zone exist on the shelf edge and seaward of the shallow fore reef zone of some reefs.

Limestone pavement, a hard, level, mostly featureless substrate or hard bottom, occurs nearly ubiquitously within the St. Croix Coral Reef APC. Pavement exists in waters up to seventy feet in depth. Sea fans and whips (gorgonians) and scattered corals are commonly found in this zone.

Algal ridges are mounds of encrusting coralline algae. The upper most portions of the algal ridge can extend three feet above normal sea level. Algal ridges tolerate periodic desiccation, high wave action, and high sunlight intensity. They are commonly located on the fore reef zone of the southeastern reefs.

Davis Beach to Long Reef:

The coastline from Davis Beach to Long Reef is characterized by a 100-500 meter wide insular shelf which narrows and steepens with an increasingly bold, submerged, seaward face to the west. The shelf demonstrates a precipitous drop to depths exceeding one-thousand feet. Fringing reefs along the shelf edge conform, with some variation, to the following zones. An area of pavement exists nearshore, while seaward is a shallow reef dominated by mountainous star coral, brain coral species, leaf coral, sheet coral, rough starlet coral, finger coral species, and mustard corals (Hubbard, 1989c). Emergent shallow reefs occur offshore from Salt River Bay, North Shore, and Prosperity. In many locations, a sandy flat occurs between the nearshore pavement and the shallow reef. A more pronounced slope begins at a depth of 20 m and is located near the deep reef. Sheet and leaf corals, star corals, finger coral, mustard coral, and starlet corals are major constituents of this deep slope.

Below 60 m, coral abundance is low, and benthic cover is predominantly of coralline algae, sclerosponges (sponges forming stony, calcium carbonate skeletons), antipatharians (black corals), and gorgonians. A continuous deep reef extends eastward to Long Reef and is broken only by the submarine canyon at the entrance to Salt River Bay. For further description of the Cane Bay/Davis Beach reef, see West Indies Laboratory (1980) and Hubbard and Suchanek (1981). For further description of the Salt River Canyon area and adjacent reefs, see Adey, *et al.* (1977), Hubbard, *et al.* (1981) and Hubbard (1989d).

Long Reef and Round Reef are degraded, shallow bank-barrier reefs extending across Christiansted Harbor, save for a 80 m wide entrance gap to the east near Round Reef. Live coral cover for eastern Long Reef and Round Reef was a low 6-23 percent in the mid-1980's, compared with 18-65 percent for other reefs in the area (V.I. Marine Advisors [D. Hubbard], 1986). The fore reef zone of eastern

Long Reef is comprised of coral rubble encrusted with coralline algae and scattered colonies of elkhorn coral and mustard coral. Dominant constituents of the reef flat and back reef of eastern Long Reef includes brown algae, *Sargassum* spp.; turtle grass, *Thalassia testudinum;*, and isolated, small coral colonies, including leaf coral, *Favia fragum*, mustard coral, and encrusting fire coral. The biota of Long Reef are further described by V.I Marine Advisors [D. Hubbard] (1986).

Buck Island Platform:

Scotch Bank, a shallow sloping bank to the southwest of Buck Island, is characterized by pavement and deep reef zones supporting numerous sponges and gorgonians. The northern and eastern ends of Buck Island are protected by a barrier reef. On the northern reef, the barrier reef grades into a series of patch reefs towards the northwest. Patch reefs extend westward terminating on the insular shelf edge. A sandy beach and an extensive seagrass bed comprise the west shore.

The southeastern shore of Buck Island is separated from the reefs by a lagoon 200 m in width consisting of a sandy bottom. The sand deposit grades into a flat carbonate pavement with small colonies of fused staghorn coral. Constituents of the back reef include elkhorn coral, mountainous star coral and smooth brain coral. On lower reaches, zoanthids (esp. *Zoanthus sociatus)* and gorgonians (esp. *Pseudoplexaura* spp.), and the corals *Isophyllia* spp. and *Agaricia* spp. (leaf and sheet coral) are present. The reef crest is less than 1 m below the water surface. The reef crest is dominated by elkhorn coral and leafy fire coral, and algal ridges. The fore reef is dominated by elkhorn coral and coralline algae. Seaward of the fore reef is an extensive mixed coral flat supporting a diverse coral community dominated by mountainous star coral.

Northeast of the bank-barrier reef system on Buck Island lies an extensive gorgonian and elkhorn reef flat. Approximately 20 percent of the area displayed live coral cover in the mid-1980's (Anderson, *et. al.*, 1986). To the southeast, Buck Island Channel, dotted with small patch reefs, separates the Buck Island reef platform from Tague Bay Reef.

The reef surrounding Buck Island has been the subject of extensive scientific survey and monitoring for at least 30 years now. For a complete listing of the major Buck Island studies to date, see Gladfelter (1992). For a good introduction to the ecological community types (with maps) of the entire Buck Island platform, see Anderson, *et al.* (1986). Fish and shellfish populations of Buck Island are described by Tobias, *et al.* (1988). Several reports on sea turtle nesting at Buck Island also exist; a good overview is offered by Small (1982).

East End and Lang Bank:

Discontinuous bank-barrier reefs occur offshore from Coakley Bay and Solitude Bay. Eastward these structures become the continuous Tague Bay Reef, which is separated from the headland by several hundred meters of sandy lagoon. The shallow lagoons landward of the reef are characterized by small patch reefs, seagrasses, and calcareous algae (*Penicillus* spp. and *Halimeda* spp.). Other constituents include gorgonians, elkhorn coral, mustard coral and fire corals. Coral rubble and sand are common in the mixed coral zone. Within the shallow fore reef zone are stands of elkhorn coral, club finger coral, staghorn coral, mountainous star coral and braincorals. Another reef extends eastward and parallel to Tague Bay Reef located at Channel Rock, and displays similar community structure to that of Tague Bay Reef. An artificial reef constructed in 1976 of 400 concrete blocks is located north of Tague Bay Reef (Adey, *et al.*, 1977).

Fringing reefs occur on the east end of St. Croix from Cottongarden Point to Hughes Point. These reefs lie adjacent to the shore and are characterized by a 100 m wide shallow fore reef zone and a seaward deep reef zone. A sandy flat separates the shoreline reef from an extensive pavement which is part of Lang Bank. For further description of Tague Bay Reef see, Adey, *et al.* (1977). Earlier descriptions are contained in Ogden, *et al.* (1972).

Lang Bank is an offshore pavement extending from the barrier reefs. It encompasses the area from the eastern shoreline to the shelf edge. The pavement of Lang Bank extends 15 km to the east from Point Udal. On the reefs to the southeast of St. Croix, the pavement is 5 km wide coinciding with a decrease in the width of the insular shelf. Water depth averages between 9-18 m and the dominant constituents of the hard pavement are soft corals and sponges, with only scattered coral heads and very little elkhorn coral. Patches of sand are common throughout the area (Adey, *et al.*, 1977, as reported in Wells, 1988).

Southeastern Reef:

The southeastern St. Croix reef system extends from the Great Pond Bay lagoon eastward to the fringing reefs enveloping Point Udall, and is part of a 4000-5000 year old, 23 mi long bank-barrier reef which rings virtually the entire East End (Adey, *et al.*, 1979). The southeastern reefs are especially interesting, because all of the geological and ecological successional stages, young to old, are present (or at least were present prior to Hurricane Hugo) [Adey, *et al.*, 1979]. The bays at Turner Hole, Robin Bay, Fancy Bay, and Great Pond Bay are examples of moderate sized lagoons fronted by bank-barrier reef structures.

Several patch reefs and seagrass beds occur within the Great Pond Bay lagoon. The western edge of the lagoon is a pavement with scattered corals. Seaward of the lagoon is a well developed barrier reef. Patches of mixed coral reef occur landward of the reef crest. Within the shallow fore reef zone are live and dead coral stands elkhorn coral, fire coral, starlet coral, brain coral and mustard coral. Seaward of the barrier reef the benthic community is best described by a deep reef zone interspersed with pavement. Along the southeastern shelf edge is located a deep reef in water depths of 30-50 m.

Extensive mangrove stands are located in Great Pond (itself an APC and proposed SNA), a nearly enclosed "salt pond", normally connected by a narrow, shallow channel to Great Pond Bay.

The near shore environment of Robin Bay, Rod Bay, and Turner Hole demonstrate similar marine benthic environments and will be discussed jointly. The bays are each about 100-300 m in length. Benthic cover includes seagrasses, turf-like algae, patch reefs, and sand flats. A continuous bank-barrier reef system extends from Great Pond Bay to South Grapetree. The mixed coral zone of the back reef consists of broken and cemented coral fragments, mustard coral, mountainous star coral, brain coral and starlet coral.

The reef structure in Turner Hole demonstrates variation in that an extensive algal ridge has formed along the inner reef crest. Coralline algae *(Lithophyllum congestum* and *Porolithon pachydermum*), and fire corals are dominant constituents. This is separated from an outer shallow fore reef by a sand bottom channel. The shallow fore reef has gorgonians, head corals, and elkhorn coral as dominant constituents. Seaward of the barrier reef is a 5 km wide shelf. The benthic environment consists of sand flat and pavement with sparse coral and algal cover.

2.4.3 Environmental parameters

Coral reef distribution is limited by the physiological requirements of reef-building organisms. Such organisms thrive within a narrow range of environmental parameters for light, temperature, water clarity, salinity, oxygen, and nutrients. Corals thrive in the clear, shallow, low nutrient waters of the tropics, and their distribution and abundance can be affected by even minor changes to these parameters.

Light is a limiting factor for coral distribution. Corals require high light transmission for photosynthesis by their symbiotic zooxanthellae (microscopic single celled algae). The lower depth limit for coral growth can vary considerably (depending on the type of coral involved and the degree of water clarity), but is rarely below 50 m, and is usually less than 30 m (Wells, 1988).

Corals within the APC are exposed to natural ambient water temperatures between 25.0-29.5°C (Quinn and Kojis, ms.), and lagoon water temperatures between 23°C and 30°C. Thus, natural ambient water temperatures in the APC are close to the upper lethal limit for corals, which are intolerant of temperatures much below 20°C and above 30-35°C (Fujita, *et al.*, 1992).

Sediments carried by terrestrial runoff are one of the most significant inhibitors of coral growth due to turbidity, and the consequent reduction in the amount of light that is allowed to penetrate to the benthic environment. Sediments in the water column have the same effect as shading, and can result in both lethal and sub-lethal effects on corals (Loya, 1976; Rogers, 1979, 1990).

Photosynthetic zooxanthellae (symbiotic algae found in coral tissue) cannot tolerate prolonged reduced light transmission, and when stressed are emitted by corals, resulting in "bleaching" (or loss of color) of the coral. This results in the coral exhibiting a slower growth rate and metabolism (photosynthesis and respiration) and lower reproductive rate.

Sedimentation, besides reducing light levels, often affects the behavior of corals. In trying to rid their surfaces of sediment corals may extrude their mesenterial filaments and produce copious amounts of mucus. In some cases, disease may appear (Wells, 1988). These responses to sedimentation require the corals to expend energy that would otherwise be used for growth and reproduction. Where sedimentation is chronic, reef building corals are killed and the reef community structure and function is altered. In most cases the loss of reef building corals and increase in limestone boring organisms weakens the reef framework. The reef is usually colonized by benthic algae as corals die (Rogers, 1979).

Sediments settling from turbid waters not only reduce the amount of light transmitted but also retard coral larvae recruitment (Rogers, 1990). Where soft sediments prevail in the benthic environment, coral larvae recruitment is inhibited because they require a sediment free, hard surface on which to attach. Corals can not become established or proliferate near shores which experience substantial natural erosion of headlands. The same effect is observed in areas exposed to chronic turbidity and sedimentation due to heavy terrestrial runoff. Scleractinian corals appear to be the most sediment intolerant species (Hubbard, 1987). Mean sedimentation rates in areas not subject to man-induced sediment stress in the Virgin Islands are < 1 to around 10 mg cm^{-2} per day; mean suspended sediment concentrations are < 10 mg l^{-1} (Rogers, 1990).

Reef communities poorly tolerate hyposaline (low salinity) or hypersaline (high salinity) conditions. Salinities less than 25-30 ppt or greater than 50-70 ppt are lethal to many coral species (Fujita, *et al.*, 1992). Ambient water salinity for the St. Croix reef system is generally constant at 35 ppt, and only rarely drops below 34 ppt following heavy rains.

Coral growth is improved when the overlying waters are well oxygenated by current or wave action. However, overly intense wave action in shallow waters retards coral growth and affects coral community structure. As mentioned above, coralline algae tends to predominate under such conditions, allowing the formation of algal ridges.

Tropical waters are normally clear and have normally low concentrations of dissolved nutrients, and it is under such conditions that corals thrive. The symbiotic relationship that corals have with zooxanthellae allows for growth in the low-nutrient environment, however, elevated concentrations of dissolved nutrients, especially organic phosphorus, can have profound impacts on reef structure and function (section 2.4.4).

2.4.4 Potential adverse impacts and recovery

Although the annual probability of a hurricane in the Virgin Islands is once every 16 years (Bowden, 1974), as seen above (section 2.3.4), hurricanes have either struck St. Croix or passed close enough to impart reef damage at least six times during the past 15 years. Whether or not hurricanes and tropical storms directly pass over an island, they are significant disturbances which can affect the reef ecosystem through physical destruction of corals, increased sedimentation and turbidity, increased nutrient concentration, and lowered salinity from freshwater runoff. The physical effects from large swells and wave action can be extremely damaging, particularly to exposed shallow reef coral communities (Rogers, *et al.*, 1982). Damage to reefs is likely to be influenced by water depth, type of pre-storm substrate, and reef orientation (Hubbard, *et al.*, 1991).

Storm perturbations affect the diversity, structure, function, and fitness of the coral reef system. Reef diversity depends heavily on spatial heterogeneity, maximum productivity, and maintenance of the natural grazing balance (section 2.4.1) [Adey, *et al.*, 1979]. Physical damage to reefs can reduce their spatial heterogeneity (i.e., the nooks, crannies and holes that provide shelter and settlement surfaces), and thus shift the balance of dominant species. Once such a shift occurs, increased predation and competition for space usually follows, and overall productivity and the natural grazing balance of the system can be quickly altered. Thus, storm damage, can have profound localized effects on reef structure, function, and overall productivity. Such effects were studied on St. Croix following hurricanes David and Frederik, and significant alterations in staghorn and elkhorn coral communities were observed (Rogers, *et. al.*, 1980). Similar and other effects of Hurricane Hugo are described by Hubbard, *et al.* (1991) and Island Resources Foundation (1991).

Despite (or rather because of) the disturbance to reef communities brought about by hurricane damage, such events play an important role in maintaining reef structure and biodiversity over the long-term (Wells, 1988). Hubbard (1989b) suggests that reef type is in fact a function of prevailing wave energy and hurricane impacts. He cites the occurrence of the dominant elkhorn coral community on the north shores of St. Croix as indicative of the protection afforded these reefs by the island from the full impact of hurricanes or tropical storms. In contrast, the presence of numerous and well developed algal ridges along the southeastern shore is indicative of a more frequent occurrence of high energy wave impacts from storms.

Recovery from the effects of a hurricane or tropical storm varies according to the intensity and duration of the disturbance, as well as mitigating factors. In general, coral reefs appear to recover productivity and diversity quickly in response to temporary physical disturbances (Fujita, *et al.*, 1992). Wells (1988) suggests that recovery rates can be on the order of 20-50 years for complex reefs (with many head corals), to only a few years for simpler reefs (e.g., monotypic reefs dominated by branching corals such as staghorn and elkhorn corals).

Adverse impacts to corals result from increased water temperatures, and evidence suggests that the coral bleaching observed worldwide in recent years may be linked to high water temperatures (Brown and Ogden, 1993). It is known that zooxanthellae tolerate a narrow temperature range, and even slight elevations in water temperature (i.e, as little as 4-5°C) will cause coral polyps to emit their zooxanthellae (resulting in bleaching). Water temperature shifts of this magnitude can accompany the meteorological phenomenon known as "El Nino Southern Oscillation" or ENSO.

ENSO is a global weather disturbance which recurs periodically (possibly every 3-8 years) and which can last up to 18 months. During an ENSO event, meteorological patterns worldwide are disrupted, often resulting in changes to regional temperatures and rainfall amounts and patterns. Elevated sea temperatures occurred in the Indo-Pacific during the 1982-83 ENSO event, and are believed to have caused the widespread coral bleaching observed in that region at that time (Lang, *et al.*, 1992). During the summer and fall of 1987, and again in 1991, the Western Atlantic and Caribbean experienced further bleaching events (Williams and Williams, 1987; Fujita, *et al.*, 1992; Brown and Ogden, 1993). While local discoloration of reef corals has been reported throughout the past century, this type of regional, mass bleaching event has been reported only during the past decade (Lang, *et al.*, 1992).

Biological disturbance to the reef system can also be quite significant. Coral diseases, for example, can affect reef community structure and ecosystem balance. Two prominent coral diseases -- white-band and black-band disease -- have spread throughout the region in separate episodes during the past decade. Diseases can be devastating and have long lasting effects on reef population dynamics (Gladfelter, 1982). During a white-band disease outbreak in the early 1980's, Gladfelter (1982) observed the following types of reef community changes due to the die-off of elkhorn coral: (1) a decrease in the structural complexity of the reef surface; (2) a decrease in live coral cover; and hence (3) a reduction in carbonate production; (4) an increase in both filamentous and crustose algae; and (5) an increase in the abundance and diversity of small invertebrates, including scavengers on necrotic coral tissue, borers, and herbivorous gastropods (Gladfelter, 1982 as summarized in Gladfelter, 1992). Tobias, *et al.* (1988) discuss how fish populations at Buck Island reef have been adversely affected by coral losses attributed to white-band disease and the unrelated long-spined sea urchin mortality. The causative agent for white-band disease is not presently known.

Black-band disease presents a different risk to corals. The causative agent is the microfilamentous blue-green alga (*Phormidium* spp.). The disease is well known for its ability to quickly infest the coral's tissue leaving only the skeleton behind, which then becomes overgrown by macroalgae (LaPointe, 1989). Black-band disease is especially in the mountainous and cavernous star corals *(Montastrea cavernosa* and *M. annularis)*. Bythell, *et al.* (1989) report that both white-band and black-band disease are still present on the St. Croix reef to varying degrees.

The ultimate severity and duration of adverse effects on a coral reef from any disturbance depends largely on the cumulative stress on corals at a given time. In other words, the more stressors impacting a reef the lower the ecosystems resistance against additional stress.

The effects of suspended sediments (turbidity) and of sedimentation on corals were briefly discussed above (section 2.4.2). While numerous studies have discussed sedimentation effects on corals, there is no consensus as yet regarding quantitative limits above which reefs suffer. Rogers (1990) provides mean sedimentation rates and suspended sediment concentrations (section 2.4.2). Rogers (1979) demonstrated that shading of the staghorn coral, *Acropora cervicornis,* can cause coral bleaching and a series of changes leading to eventual take-over of the coral by benthic algae. In general, marine systems can tolerate short-term sediment loading, but do not fare well under conditions of chronic turbidity or sedimentation (Rogers, 1979; Hubbard, 1987).

Under such conditions, a general change in reef community composition ensues. Less sediment-tolerant species (e.g., the large brain corals, *Diploria* spp.) give way to the more sediment-tolerant branching corals (e.g., *Porites* spp.), sponges, and benthic algae (Butler, 1993). Increased turbidity and sedimentation results from a number of sources, among them increased and poorly planned upland development, filling, loss of mangroves and seagrass beds, dredging, and resuspension of fines by boat propeller wash.

Eutrophication results from the addition of nutrients to a water body which results in excessive primary production (plant growth). In shallow water this can cause depletion of the oxygen content of the water body. Dissolved organic phosphorus may be the most important nutrient that stimulates algal blooms and reduces coral cover on reefs (La Pointe, 1989). As already mentioned, corals and their endosymbionts (zooxanthellae) are adapted to the low-nutrient conditions of tropical waters. Algal production is normally limited by low levels of nitrogen and phosphorus in tropical waters. The

tight nutrient cycling of corals (made possible by the symbiotic relationship) enables high productivity in waters low in nutrients.

But such endosymbiont associations are not able to take immediate advantage of nutrient pulses as are algae or small suspension-feeding animals such as sponges and barnacles. These two groups are able to accelerate growth faster than corals, and do so easily when additional nutrients are supplied to the marine environment such as from terrestrial runoff or sewage discharge. When nutrient levels increase sufficiently to allow waters to become eutrophic, a shift in dominance occurs from corals to benthic algae. Normally, grazing herbivorous fishes and/or echinoids keep the benthic algae in check. But under nutrient-rich conditions, they are unable to keep pace with the rapid increase in benthic algal biomass. Such is or has been the condition of many reefs throughout the world where coastal waters have received massive inputs of nutrients (e.g., Kāneohe Bay, Florida Reef Tract, and portions of the Great Barrier Reef) [Birkeland, 1990].

As nutrient inputs increase even more, heterotrophic suspension-feeding organisms (consuming organic matter) begin to dominate over phototrophs (nourished through photosynthesis). Researchers have documented a five-fold increase in the biomass of heterotrophic sponges on a coral reef in the Caribbean when a sewage outfall began operation (Birkeland, 1990). Tomascik and Sander (1985) discuss the effects of nutrient loading on the mountainous star coral, *Montastrea annularis,* in Barbados. Biomonitoring studies indicated adverse effects on coral community structure down current from the Red Point sewage outfall on St. Thomas (Coulston, 1987).

The timing and duration of sediment and nutrient loading are important factors in how these impacts will affect overall age structure and species composition of the reef community. Marine species that have planktotrophic larvae (i.e., that feed on phytoplankton) have generally adapted a spawning strategy that times spawning to coincide with natural (seasonal) abundance of nutrients (e.g., peak rainfall season) [Birkeland, 1990]. This strategy increases the probability for larval recruits to survive the plankton stage through metamorphosis to adulthood. Such a strategy should be understood for its potential to affect the balance of the reef ecosystem, as many marine organisms have planktotrophic larvae, including several that might affect (either directly or indirectly) the overall grazing balance. As discussed previously, greater numbers and densities of certain reef populations can lead to increased competition and predation or grazing, and the entire system can become quickly unbalanced.

Although reefs are areas of high productivity, low fishery yield is the norm. As seen above (section 2.4.1) coral reefs are characterized by populations of long-lived, generally large and slow-growing individuals (e.g., corals, groupers, etc). Unfortunately, such a growth strategy does not well support a commercial fishery, or even a subsistence or "traditional" fishery in many cases. The fact is that reef fish and invertebrates are easily overharvested (i.e., past sustainable yield), simply because of the irregular recruitment, slow growth, longevity, and low rates of population turnover of preferred reef fish such as groupers and snappers (Birkeland, 1990). For the same reasons, corals, too, (especially Black corals), cannot sustain any kind of harvest that would surpass the slow accumulation of biomass that typifies coral growth.

Other sources of stress applicable to the St. Croix coral reef system include industrial pollution and petroleum product spills in the marine environment. Industrial pollution includes both air and water discharges, both of which can involve chronic (i.e., long-term) stress on reef communities. Thermal discharge from power and/or desalination plants, such as exists at the WAPA station inside Long Reef at Christiansted Harbor, can be especially deleterious to the health and productivity of nearby reef systems. Ambient water temperature increases of as little as 4°C can be lethal to coral (Wells, 1988; Fujita, *et al.*, 1992). As seen above, elevated water temperature can lead to expulsion of the zooxanthellae, resulting in bleaching.

Oil spills and/or the continual release of oil/grease into marine waters (as near a marina and from urban storm drains), will adversely affect coral health if the petroleum products come into direct contact with the coral polyps. Although there is no conclusive evidence that oil floating above corals damages the adult colonies, problems are known to arise with direct contact. Thus, emergent reefs at low tide are especially vulnerable to petroleum product spills, and should be given special attention in resource management and response plans (Johannes, 1975). Species-specific sensitivities to petroleum products are yet to be fully identified. It should be noted that the use of toxic chemical detergents in the clean-up of oil spills has the potential to inflict more damage to corals than from the spill itself.

Oil spills may have a more profound affect on surface plankton, including the eggs and larvae of corals and other marine organisms. Many Caribbean coral species spawn in synchrony only a few days of each year. These species generally release buoyant eggs and sperm that remain on the surface of the water for several days. Any toxic material, such as oil, will readily kill the coral gametes and developing larvae reducing reproduction success for that year.

Finally, recreational uses of the marine environment exert cumulative impacts on reef health and productivity that is cause for increasing concern among scientists and reef system managers. Snorkeling, diving, fishing, reef-walking, and the use of pleasure boats each contribute (albeit differentially) to the cumulative damage of coral reefs. Of these, perhaps the greatest, growing concern is the damage inflicted by anchors, anchor chains, and ship "groundings" on reefs. Rogers (1991, 1992) has documented such damage on reefs of the V.I. National Park on St. John. The damage there has been so great, and increasing almost exponentially, that the National Park Service has moved to prohibit vessels of 69 m in length from anchoring inside the Park boundary (Marion and Rogers, 1992). Other types of visitor impacts that need to be addressed in a Comprehensive Study and proposal for a management plan are discussed in section 4.2.

2.4.5 Endangered species

The U.S. Endangered Species Act of 1973 (16 USC Sec. 1531) defines "endangered species" to mean a species or subspecies that is in imminent danger of extinction throughout all or a significant portion of its range. "Threatened species" are those likely to become endangered in the foreseeable future unless current trends are reversed. Such species are protected by Federal law; neither the whole animal or any products from it may be taken, sold, or possessed. Alteration of the habitat in which any of these species occurs may be, in certain cases, prohibited or constrained.

The V.I. Legislature has also passed endangered species legislation. Known as the Indigenous and Endangered Species Act of 1990, the bill (Act 5665), signed into law in December 1990, authorizes the Commissioner of DPNR to promulgate a list of endangered and threatened species in the Virgin Islands. The V.I. Government, Department of Planning and Natural Resources, Division of Fish and Wildlife maintains a list of locally endangered or threatened species.

The following endangered or threatened species are either known to occur, or have a reasonable probability of occurring, within the St. Croix Coral Reef System APC (pers. comm., B. Knowles, DPNR/DFW):

Federally listed:

1. Green sea turtle *(Chelonia mydas)* [threatened];
2. Hawksbill sea turtle *(Eretmochelys imbricata)*;
3. Leatherback sea turtle *(Dermochelys coriacea)*;
4. Brown pelican *(Pelecanus occidentalis)*;
5. Roseate tern *(Sterna dougallii)* [threatened]; and
6. Humpback whale *(Megaptera novaengliae)*.

Locally listed:

1. White-tailed tropicbird *(Phaethon lepturus)*;
2. Least Tern *(Sterna antillarum)*;
3. Great blue heron *(Ardea herodius)*;
4. Great (common) egret *(Casmerodius albus)*;
5. Black-crowned night heron *(Nycticorax)*;
6. Fisherman bat *(Noctilio leporinus)*;
7. Black coral, Order Antipatharia; and
8. Jewfish *(Epinephelus itajara)*.

2.5 Cultural Resources

2.5.1 Prehistoric

There are no known prehistoric resources within the APC, however the potential exists for prehistoric sites to be found along the shore. Evidence suggests that the shores of St. Croix have been eroding for hundreds of years, allowing for the possibility that prehistoric settlements along the coast have, since abandoned, been subject to erosion and/or covering by sand and other debris. The potential for such discovery is illustrated by a preceramic site on Estate Betty's Hope of the south shore (dating to 2000 B.C.), which sits on the existing shoreline and is subject to continuing erosion. The Aklis site, a prehistoric site at the Sandy Point National Wildlife Refuge, is similarly situated. Prehistoric artifacts have been found eroding from embankments on Buck Island and Green Cay (pers. comm., W. Cissel, National Park Service).

2.5.2 Historic

Similarly, (with the exception of shipwreck debris, see below), there are no known historic sites (i.e., structures or settlements) within the APC, however the potential exists for discovery of historic sites along eroded shorelines. One potential site may have been recently exposed. Although as yet not confirmed, evidence suggests that an early colonial (c. 1788) coastal defense cannon battery has been exposed by eroding or shifting sands at Coakley Bay, on St. Croix's East End (pers. comm., W. Cissel, National Park Service).

Numerous shipwrecks and vessel debris litter the sea floor within the APC. The waters around Buck Island, for example, have been known throughout history as a "graveyard for ships". Similarly, the reef area along the north coast between Davis Beach and Salt River Bay is strewn with historic shipwrecks and artifacts, the majority of which come from the period 1750-1860 (pers. comm., W. Cissel, National Park Service). There has not yet been a systematic magnetometer survey of the waters within the APC.

2.6 Built Environment

2.6.1 Ports

There is one port within or adjacent to the APC; it is located in Christiansted Harbor, on the island's north shore. Resource management issues and recommendations for the port are dealt with in the Comprehensive Analytic Study for the Christiansted Waterfront APC (DPNR/DCZM, 1993a).

2.6.2 Water Systems

The water system for St. Croix, including the power generation and desalination plant which discharge effluent into Christiansted Harbor, is described in the Comprehensive Analytic Study for the Christiansted Waterfront APC. Resource management issues and recommendations for those facilities are dealt with in that document (DPNR/DCZM, 1993a).

2.6.3 Wastewater Systems

The wastewater collection and treatment system for St. Croix, including the emergency bypass outfall at the LBJ pump station in Christiansted Harbor, is described in the Comprehensive Analytic Study for the Christiansted Waterfront APC. Resource management issues and recommendations for those facilities are dealt with in that document (DPNR/DCZM, 1993a). Individual sewage treatment package plants are utilized by various coastal developments adjacent to the APC, including those found at Davis Beach, the Southgate Pond/Chenay Bay area, and Grapetree Bay. Stormwater drains are an additional source of wastewater discharge to the marine environment, especially within the Christiansted area, where the sewage collection system is old and in need of repair.

2.6.4 Energy Systems

The electricity system for St. Croix, including the power generation and desalination plant which discharge effluent into Christiansted Harbor, is described in the Comprehensive Analytic Study for the Christiansted Waterfront APC. Resource management issues and recommendations for those facilities are dealt with in that document (DPNR/DCZM, 1993a).

2.6.5 Solid Waste Disposal Systems

The solid waste collection and disposal system for St. Croix, including the Anguilla landfill on St. Croix's southshore, is described in the Comprehensive Analytic Study for the Southshore Industrial Area APC. Resource management issues and recommendations related to solid waste collection and disposal are dealt with in that document (DPNR/DCZM, 1993f).

3. RESOURCE USE, USE CONFLICTS, AND ADVERSE IMPACTS

3.1 Resource Use

Although considerable dredging, filling, and bulkheading has been undertaken at numerous places on St. Croix, the vast length of the APC shoreline precludes a comprehensive description of those activities here. Many such coastal development activities are described and dealt with in the Comprehensive Analytic Studies for other APC's, including Christiansted Harbor, East End, Great Pond Bay, Salt River Bay, and Southgate Pond/Chenay Bay (DPNR/DCZM, 1993a, 1993c, 1993d, 1993e, 1993f). These activities are especially inimical to the reef system when they involve the destruction of productive habitat (e.g., mangroves, seagrass beds, or live coral), or are undertaken without due regard for control of sediments released into the water column.

Most direct human uses of the St Croix Coral Reef System APC, however, fall in the categories of recreational activities or commercial fishing. Snorkeling, SCUBA diving, reef-walking, surfing, wind surfing, the use of jet skis, swimming, skiing, and pleasure boating represent the range of recreational activities commonly found in various parts of the APC. In addition, spearfishing, hook-and-line fishing, gill netting, and the use of fish traps (pots) are the principal techniques used by a wide range of fishermen who gain their livelihood from or spend their leisure time on the reef system. Although hard data are scarce, it is fair to say that, these activities have increased as the population of residents and visitors on St. Croix has increased.

From previous discussion on the effects of sediment and nutrient loading on the reef system, it should be clear that other human uses of the marine environment exert considerable adverse impacts as well. The discharge of sewage, industrial pollution, oil/grease, and terrestrial sediments are perhaps the most significant and growing threat to the vitality of coral reefs worldwide, including the St. Croix reef system. Once again, these particular uses for the reef system APC have been described and dealt with in the other relevant APC Comprehensive Analytic Study.

3.2 Use Conflicts

Conflict within the APC between user groups is not readily observable or often reported, although such conflict is inevitable within such a large area. Many such conflicts center around the use of loud jet skis or speeding motor boats within or adjacent to crowded swimming beaches. Comprehensive Analytic Studies for the Christiansted Waterfront, Salt River Bay, and Southgate Pond/Chenay Bay APC's, in particular, mention the growing incidence of conflict between "passive" and "non-passive" recreationalists. Competition for mooring space is a growing issue in some locales.

Conflicts between a given user group and the natural environment are, however, more observable and widespread, as described in the following section.

3.3 Adverse Impacts

3.3.1 Water Quality

Adverse impacts to water quality are generally restricted to nearshore waters within the APC, and arise largely from land-based sources of marine pollution. Sediment, nutrient, and chemical laden terrestrial runoff is perhaps the largest single and widespread contributor to degraded marine water quality, although significant, mostly localized point source discharges exist as well. As far as the APC is concerned, these latter sources are described, with management recommendations offered, in the other relevant APC Comprehensive Analytic Studies already mentioned. They include various marina/boat repair operations (toxic compounds), the power generating and desalination facility in Christiansted Harbor (thermal pollution and toxic compounds), and storm drains and emergency sewage bypass discharges (toxic compounds and excessive nutrients) in the same locale. Concern for cumulative impacts arising from vessel wastes (nutrients, fecal coliform, and oil/grease residues from bilge pumping) is also discussed in the Salt River Bay, Christiansted Harbor, and Southgate Pond/Chenay Bay APC Comprehensive Analytic Studies.

In the absence of a more comprehensive water quality monitoring program, it is probably fair to say that turbidity, fecal coliform, and nutrients are of most concern for overall water quality within the APC. Certainly, toxic compounds (including heavy metals, pesticides, and industrial toxicants) are of concern in some locales (e.g., Salt River Marina, Gallows Bay, west Christiansted Harbor, Green Cay Marina at Southgate Pond, etc.), but these affects appear to be local. Although most toxic compounds are bound in bottom sediments, the potential exists for these materials to enter the water column, and thus affect more distant biological communities. Little is known of the synergistic effects of various toxic compounds on aquatic organisms.

Water quality within the APC is determined in large part by the amount and quality of nonpoint sources of pollution which enter coastal waters. Terrestrial surface runoff and groundwater leachate, from poorly designed or functioning septic tank systems, are of principal concern. Although difficult to quantify or assess, the cumulative impacts from these sources can be significant. Groundwater leachate is a source of fecal coliform and nutrients (e.g., nitrogen, phosphorus, ammonia, nitrate, nitrite, etc.). Surface runoff can carry a variety of toxic compounds, nutrients, and significant amounts of sediment. For example, sediment discharge from a single, three acre construction site located in the Rio Piedras watershed above San Juan, Puerto Rico, was calculated to be approximately one ton during a 0.5 inch (12.7 mm) rainfall which fell in a 30 minute period (Gellis, 1991). The study documented that annual sediment yields ranging from 21,600 to 33,200 tons <u>per square mile</u> were exhibited by the same developing, suburban watershed.

3.3.2 Air Quality

Air quality within the APC is generally considered to be excellent. There are no known adverse impacts on the reef system from poor air quality.

3.3.3 Noise Pollution

Aside from the typical levels of noise associated with motorized watercraft, there are no known major sources of noise pollution within the APC. The use of jet skis is a localized source of noise pollution generally confined to resort areas.

3.3.4 Impacts to Biological Resources

Except for the area surrounding Buck Island and that adjacent to Tague Bay (near the of the former West Indies Laboratory), the status and trends of marine ecosystems within the APC is not well known. Over 50 percent of the mangroves on St. Croix have been destroyed during the past 200 years; most within the past 50 years. As mentioned above (section 2.4.1), remaining mangrove stands within or adjacent to the APC are located at Rust-op-twist, Salt River Bay, Altona Lagoon, Southgate Pond, and Great Pond Bay. The status of seagrass beds is not as well known, however, and with the exception of the Buck Island Reef National Monument, there has not been a recent, systematic survey and mapping effort of seagrass beds within the APC. Likewise, an assessment of live coral coverage and the general state of health of the reef system has not been completed for the entire APC. Certain portions of the reef system have been surveyed in detail, most recently in the months following Hurricane Hugo in 1989.

Several destructive fishing techniques remain in practice despite their well known impacts to biological communities. Among these, spearfishing, the use of SCUBA gear for fishing, and gill netting are perhaps the most damaging (pers. comm., W. Tobias, DPNR/DFW). Spearfishing and the use of SCUBA gear for fishing are especially "efficient" techniques, and allow for a given area to be quickly overfished for a given species or group of species. Gill netting, on the other hand, is both efficient and non-selective, resulting in the catch of all age classes (i.e., both juveniles and adults), and a broad range of species of which many are often not usable. Gill nets are heavily used for the harvest of herbivorous fish such as scarids (parrotfish) and acanthurids (surgeonfish). These fish feed on benthic algae and are the primary organisms keeping benthic algal growth in check, since the population collapse of the long-spined sea urchin (*Diadema antillarum*). Fish traps (or pots) are likewise non-selective, and have the additional potential for physical destruction of live coral. Fish traps can cover an area of 4 square meters. Moreover, if a trap is lost, it will continue to catch fish for several years, or until it is rendered non-functional by the elements. Traps can be constructed so that at least part of the trap degrades quickly if lost.

Together, these fishing techniques and/or gear technologies have vastly undermined the sustainability of several marine resources, including the spiny lobster *(Panulirus argus)*, conch *(Strombus gigas)*, Nassau grouper (*Epinephelus striatus*), jewfish (*Epinephelus itajara*), and black coral (Order Antipatharia) to name but a few.

As mentioned above (section 2.4.4), the loss or significant reduction of a given marine population can result in a "domino effect" and major alterations to the composition and function of a reef community. When herbivorous fish are depleted (either through overfishing or predation), they can no longer consume enough algae to keep it from overgrowing the reef. Experiments in Belize, in which areas of back reef were enclosed to prevent grazing by fishes, resulted in a significant increase in benthic algae within a 10 week period. Coralline algae and hard corals (finger corals) decreased dramatically in numbers, and became overgrown with algae (Butler, *et al.*, 1993). Similar results were obtained with the experimental removal of thousands of long-spined sea urchin (*Diadema antillarum*) individuals from a Tague Bay Reef in the mid-1970's (Ogden, 1976).

These types of "biological adjustments" of the reef system are mentioned as a reminder of the subtle (and sometimes not so subtle) and often synergistic effects that occur when a component of the marine ecosystem is altered, be it through natural or man-made causes. The entire range of potential impacts to the reef system -- sedimentation, turbidity, nutrient input, water-borne pathogens, toxic compounds, salinity and temperature changes, and physical damage from storms, hurricanes, anchors, or reef-walking, to name a few -- combine to maintain a certain level of stress on the reef system, resulting in sub-lethal effects of reduced health and productivity. Such effects more often than not go unnoticed in the short-term, and only become evident through long-term observation, or when change has progressed too far to halt or reverse the stressor agent. Thus, it is difficult to fully quantify the present "state of health" of the coral reef system. A general characterization, however, offered by most long-time residents and observers of the St. Croix reef is that live coral coverage and the abundance of fishery resources have significantly declined during the past 30 years.

3.3.5 Impacts to Cultural Resources

Shipwrecks and other submerged artifacts are subject to removal or damage by SCUBA divers and/or dredge and fill operations. The overall extent of such activity within the APC is not known, although reports have been made concerning the removal of certain artifacts. An example of this is cited in the Study for the Christiansted Waterfront APC. In 1988 a visiting diver removed an elephant tusk found on the west side of Protestant Cay in Christiansted Harbor. The tusk most likely originated from a late 18th century ship participating in the triangular trade in slaves and cargo. There being no antiquities law at the time (a situation which continues to exist today), officials were powerless to prevent the tourist from leaving the country with the valuable find (pers. comm., W. Cissel, National Park Service).

4. MANAGEMENT RECOMMENDATIONS

4.1 Policy Framework

A coral reef is an often undervalued resource that serves a multitude of functions which benefit the entire marine ecosystem and adjacent human communities. Reefs are among the most diverse and productive ecosystems of the planet, often compared to tropical rainforests in their species richness. The reef framework provides coastal storm protection by dissipating wave energy, and its various biological communities produce calcareous sediments a source of beach sand. Moreover, coral reefs provide food and shelter for adults of a large number of commercially and recreationally important fish and invertebrates. As well, reefs provide critical breeding and nursery habitat for a number of species, many of which have life cycles that are dependent on not only the coral reef, but on adjacent seagrass beds and mangroves. *Together, these three sub-systems -- coral reefs, seagrass beds, and mangroves -- are interdependent in their ecological roles.*

Clearly, a healthy reef system and its linked habitats is central to the viability of reef-based tourism and fisheries. Recreational and fishery uses of the St. Croix Coral Reef System APC are extremely important to the local economy and quality-of-life. As such, maintaining an aesthetically pleasing and productive reef are underlying desires of at least two of the largest user groups of the coral reef. *The maintenance of reef health and productivity will require that certain limitations of recreational use, and of harvest, be established in order that the topographical and biological diversity of the reef system is maintained.* This could very well lead to conflict between user groups (as it has elsewhere), unless care and attention is given to establishing an open, pluralistic process of planning and goal-setting.

Proper protection and management of the reef system must therefore begin with an agreed upon policy framework which will facilitate consensus among different "user groups", and lead to collaborative efforts needed to achieve the ultimate goals and objectives of a management plan. Several government agencies (both territorial and federal), non-governmental organizations, and indeed private landowners and commercial developers must all be brought into the loop of discussion, understanding, and cooperation.

Previous sections of this Study have introduced the complexity of issues involved with management of the reef system. It should be recognized that there are many forces -- both natural and anthropogenic -- that are at work to produce almost continual stress for the reef ecosystem. Fortunately, the reef system is well adapted to defend itself against at least some stresses, and even to achieve relatively quick replenishment, renourishment, and regrowth following severe impacts, as those associated with tropical storms and hurricanes. Such mechanisms are highly dependent on our ability to minimize the levels of chronic stress to which the system is subject. *Of fundamental importance in this regard, is the need to maintain the chemical, biological, and physical integrity of the reef system.* Equally important, especially in the event of collapse of a given biological community, there must also be maintained a steady supply of propagules (eggs, larvae, or juveniles) to restore damaged communities and maintain nutrient-cycling. Without these fundamental requirements, the overall balance of the marine ecosystem is placed in jeopardy.

Although we should certainly be concerned about and observant of a growing array of "natural" stressors, including impacts associated with global climate change and accelerated sea level rise, there is little that can be done in the immediate sense to forestall such processes. We can and must, however, maximize the potential of the natural environment to continue to adapt and survive during what will surely be stressful decades ahead. As far as the marine environment is concerned, this must involve both a unified regional effort (i.e., throughout the Wider Caribbean), and the implementation of island-specific, integrated coastal zone management plans. *In short, maintenance of the chemical, biological, and physical integrity of the reef system involves monitoring and controlling adverse impacts from all sources, including those from upland terrestrial areas and from ocean waters beyond the reef, in addition to human activities at sea.*

With these few paragraphs as introduction, the following policy framework and list of management goals for the St. Croix Coral Reef System APC are offered. Specific management measures (objectives) are offered in section 4.2.

Policy statement

The St. Croix Coral Reef System is a cornerstone of the island's economy. It has many intrinsic ecological, aesthetic, scientific, educational, and recreational values. Reef-based tourism and fisheries are current and projected mainstays of the economy, and the reef represents a cultural heritage, leisurely pursuit, and educational value not definable in dollar terms. Its chemical, biological, and physical integrity must be maintained and enhanced. Evidence suggests that the decades ahead are likely to see incrementally escalating levels of "natural" stress. It is therefore important to anticipate this change and reduce other sources of stress that can be influenced by immediate actions. As such, a precautionary approach to management of the reef system will govern how existing and proposed activities are reviewed and assessed for their adverse impacts. This will include a shift of the "burden of proof" from those opposing environmental degradation to those who will benefit economically from resource utilization. The further refinement of environmental laws and regulations, and their enforcement, will no longer solely reflect immediate human needs, but as well the needs of aquatic life, and those of the entire marine ecosystem. Conservation and enhancement of the coral reef system, rather than exploitation, will govern future action.

Management Goals

1. Maintain, restore, and/or enhance natural carrying capacity of the coral reef system. Carrying capacity is defined as the total amount (numbers or biomass) of beneficial marine life that the ecosystem or subsystem can potentially support, and is used here strictly in its ecological, and not in its social or economic, context. The natural flow and cycling of energy through and between subsystems must be maintained if carrying capacity is to be achieved. As more is learned about reef carrying capacity, man-induced disturbances to the chemical, biological, and physical integrity of the ecosystem will be strictly reviewed against carrying capacity criteria. Until such time as quantifiable carrying capacity criteria can be developed, Best Management Practices and a precautionary, conservative approach to reef management will be used.

2. Utilize an ecosystems approach when reviewing or assessing existing or proposed human uses of the coastal zone. The burden of proof that existing or proposed uses will not impart further stress or degradation to biological communities rests with the proponent of a given development. Preparation of environmental assessment reports (EAR's) will identify and offer proposed mitigation measures for all direct, indirect, and cumulative impacts of a proposed development that have the potential to adversely affect the coral reef system. Increasing attention will be given to ways by which land-based sources of marine pollution can be minimized or eliminated, including the development of site-specific watershed management plans in critical areas. Unwise and/or poorly sited coastal land use developments and human activities in the sea will not be allowed.

3. Ensure that territorial water quality standards offer meaningful protection to aquatic life. In addition to stricter standards for turbidity, pathogenic bacteria, and nutrients, revised standards will include biological criteria (biocriteria), yet to be developed for the Territory, which will recognize that natural ambient water quality conditions are optimal for ecosystem integrity. Ecosystem structure (e.g., species composition) and function (e.g., ratio of community photosynthesis to respiration) under

pristine conditions should serve as the baseline against which ecosystems are classified as to degree of damage (Gjerde and Fujita, 1992).

4. Develop a system of Marine Conservation Districts that will maximize the reef system's capacity for self-replenishment, while maintaining topographical and biological diversity to enhance overall health and productivity. This effort will recognize that different conservation districts within the APC will have different goals and management objectives (e.g., ranging from "multiple-use zones" to "strict reserves"). Although the Buck Island Reef National Monument provides some protection to reef resources within its boundary, evidence suggests that fishing pressure has altered the reef's structure and function. Moreover, current fishing regulations within the BIRNM are not restrictive enough to prevent depletion of finfish, lobster, and conch populations. Needed are "strict reserve" areas strategically located in Marine Conservation Districts throughout the APC that will allow for maximum protection of critical breeding and nursery habitat to enhance the reef system's capacity for self-replenishment.

5. Establish fishery regulations that are commensurate with the management objective of maintaining carrying capacity of the reef system. Fishery regulations will be continually re-assessed and revised, recognizing that there is no established formula for the management of multi-species coral reef fishery resources.

6. Control visitor/recreational use impacts to the reef system. Tourism and marine recreational opportunities will be developed in accordance with environmental capabilities and the long-term maintenance of high quality reef communities. This will be accomplished by influencing: (a) the amount or type of visitor use; (b) the location of visitor use; and (c) visitor behavior (Marion and Rogers, 1992).

7. Establish an effective, efficient, replicable, and relatively simple and inexpensive, long-term marine monitoring program of the coral reef system. One goal of such a program is to detect changes to the chemical, biological, or physical environment before a threshold level of degradation is attained. A second goal is to discriminate true environmental change from normal "background" environmental variation. Several different environmental parameters, including select species as bioindicators, will be evaluated for priority inclusion in the monitoring program. Budgetary support will be secured for human resource development and recurrent expenses necessary to carry out the program without interruption.

8. Develop local capacity for implementation of a sustained, scientifically validated coral reef system management plan. It is recognized that this Study and proposal for a management plan is only the precursor of continuing efforts needed to refine and upgrade a reef system protection strategy. Follow-through on these and other management goals will require dedicated effort by selected government personnel to develop and maintain coordination between the relevant governmental and non-governmental institutions, and interested citizens. Ongoing training will be needed in reef monitoring techniques, design and implementation of marine protected areas, and basic coral reef research in relation to the development of aforementioned biocriteria applicable to the Territory. The importance of appropriate budgetary, political, and administrative support for this goal cannot be overemphasized.

9. Nurture and develop public understanding and support for the goals and objectives of the coral reef system management plan. Successful marine resource protection, especially on a large geographic scale as in this APC, will require the full commitment and support of the entire citizenry. Such a goal should be given appropriate priority and attention from the beginning, recognizing that additional environmental education funds and staff time will be necessary to achieve specific objectives.

10. Protect cultural resources wherever they are found within the APC, and encourage a systematic and ongoing research effort to learn more about such resources.

11. Support, and provide leadership when necessary, for regional and international efforts that will ultimately reduce the level of stress applied to the St. Croix coral reef system.

4.2 Planning, Permitting, and Other Management Measures

The policy framework and management goals offered above are meant to provide a starting point for a continued process of problem identification (including additional user conflicts and site-specific resource protection needs), land and water use planning, and refinement of management strategies. Moreover, some of the management goals offered, for example the first one regarding carrying capacity, would perhaps more appropriately be included in an overall policy framework. Nevertheless, it is included as a primary management goal for its fundamental importance as a conceptual tool for most if not all of the management measures which follow, and one which should be given increasing scientific attention as time goes on. Initial management objectives should focus on what is most practical and achievable. [Note: Management objectives for this goal are presently difficult to formulate in the absence of more current, site-specific knowledge about the reef system. That is not to say that restoration or enhancement of the reef system is not possible; there are a number of mostly experimental techniques that have been attempted (e.g., coral transplantation, habitat enhancement , etc.). However, artificial reef restoration or enhancement is not practical in most cases because of the large expense involved. In the case of fisheries management, habitat enhancement with Fish Aggregating Devices is an important component of management objectives (see below)].

1. Water quality standards

With the exception of waters within 0.5 mile of the boundaries of the "natural barrier reef of Buck Island", which have been designated as Class "A" waters, the waters of the APC are classified as Class "B" waters pursuant to Title 12, Sections 186-3 of the V.I. Code. The designated use for Class "B" waters is "... for the propagation of desirable species of marine life and for primary contact recreation". Activities which threaten the attainment of this use are inconsistent with Title 12, Section 186 of the V.I. Code, and the policy and goals of the federal Clean Water Act (33 USC 1250 *et seq.*). Furthermore, designated uses of waters within areas classified as Outstanding National Resource Waters (ONRW) under the Clean Water Act are protected by both local (Title 12, Section 186-7) and federal (40 CFR Section 131.12) antidegradation regulations. Territorial antidegradation law states that:

> Where high quality waters constitute an outstanding national resource, such as waters of National and State parks and Wildlife Refuges and waters of exceptional

recreational or ecological significance, that water quality shall be maintained and protected.

It can clearly be argued that the waters of the St. Croix Coral Reef System APC are of national significance. Indeed, several authors have argued that coral reefs are outstanding national treasures, both precious and rare, and that the states and territories, in consultation with the USEPA, should be directed to designate all reef ecosystems in U.S. waters as ONRW (Gjerde and Fujita, 1992). Thus, the following management objectives are identified:

1. Add a new designation to the territorial water quality standards called "Outstanding National Resource Waters" (ONRW), and develop an acceptable definition of the designation in collaboration with the USEPA.

2. Designate the waters of the St. Croix Coral Reef System APC (in addition to others of the Territory) as ONRW, requiring the maintenance of existing or improved water quality.

3. Revise the territorial antidegradation regulation so that it is less vague and more specific on the intended management strategy (and other consequences) in the event that specifically defined environmental degradation occurs. Stipulate that all (new) discharges or activities that would result in water quality degradation are prohibited, and that proponents of new discharges or activities are responsible to establish that their new activity will not lower existing water quality. Information on this subject and copies of other states' antidegradation policies are available from the USEPA.

   Waters within the APC should be immediately designated Class "A" which stipulates that "Existing natural conditions shall not be changed". Specific standards relating to natural conditions should be promulgated. DPNR/DEP should be required to begin compliance with the Federal requirement to review and make needed revisions to the water quality standards every three (3) years. The following specific areas need revision and/or clarification:

4. Site-specific water quality standards should be developed to provide greater protection to high quality waters within the APC (and elsewhere in the Territory). This should include stricter standards for turbidity (NTU, TSS, and Secchi), fecal coliform, and nutrients. Site-specific standards are needed due to locally occurring variations in water quality.

5. The Water Pollution Control Act should be amended and the definition of "Waters of the Virgin Islands" changed to include wetland areas. A definition of wetland areas should be included, along with water quality standards for wetlands. [For information on water quality standards for wetlands, see "Water Quality Standards for Wetlands/National Guidance"; EPA 440/S-90-011, July 1990.]

6. To protect sensitive benthic biota and to allow for monitoring of changes to biological

communities, biocriteria should be developed for the U.S. Virgin Islands and included in territorial water quality standards. [Note: The USEPA plans to provide some general guidance to states and territories for developing biocriteria for various categories of waters during the next several years. However, the Agency has no plans as yet to develop biocriteria appropriate to tropical waters containing coral reefs, seagrass beds, or mangroves. Such will have to be a territorial initiative. For information on biological criteria, see "Biological Criteria/National Program Guidance for Surface Waters"; EPA-44-/5-90-004, April 1990; and "Draft Procedures for Initiating Narrative Biological Criteria"; by G.R. Gibson, USEPA, August 1991.]

"Notwithstanding the need for biocriteria, where signs of reef degradation are evident, the absence of biocriteria should not be used to delay a freeze on existing emissions and discharges, and a prohibition on new activities that cannot be proven harmless to coral reef integrity." (Gjerde and Fujita, 1992).

7. The Water Pollution Control Act should be amended to adopt criteria for the 132 toxic pollutants for which criteria have been published under the Clean Water Act, Section 304(a). An alternative is to specify that future standards for toxic pollutants are to be consistent with the Clean Water Act, Section 303(c)(b), and the National Toxics Rule (NTR). [Note: Thus far, all states and territories, with the exception of the USVI, have either adopted their own regulations for these pollutants or have been required to comply with the NTR.]

8. Specific criteria concerning additional nutrients, such as ammonia, nitrate, and nitrite, should be developed and added to territorial water quality standards. Thus far, only standards for phosphorus exist; this standard too should be evaluated and revised if needed to ensure that sensitive marine biota are adequately protected. Bear in mind that evidence suggests that oceanic island reef ecosystems may be even more vulnerable to increased nutrient input than ecosystems that are subject to normally high nutrient and sediment inputs (e.g., lagoons of high islands, near mouths of large rivers, upwelling regions, continental reef systems, etc.) [Birkeland, 1990].

In addition to the above suggested changes to the Water Pollution Control Act, DPNR/DEP should undertake the following:

9. Designate critically sensitive areas of the reef system as "no discharge zones" and "no dredging zones". Prevent further issuance of TPDES and dredge permits in these areas. All dischargers (existing and proposed) should be required to meet water quality standards at "end-of-pipe". That is, no mixing zones should be allowed in critically sensitive areas.

10. Implement a stormwater discharge permit system in critically sensitive areas and problematical watersheds.

Finally, the following concepts should be kept in mind regarding the importance of maintaining high water quality for the health of the reef system:

a. The reef system's capacity to restore high productivity and biodiversity following disturbance is generally good, but only if there is a quick return to high water quality and the natural range of other physiological conditions.

b. Polluted water inhibits recovery; calcareous algal growth and the settlement of new coral larval recruits are inhibited by encrusting organisms that thrive on sewage.

c. Detergents have been found to be one of the larger constituents of sanitary sewage effluent and can have devastating effects on corals, mainly the soft corals (e.g., fan corals). Detergents with phosphates enhance phytoplankton production, reducing the survivability of some larval stages of reef marine fauna, and contribute to reducing light penetration through the water column during excessive phytoplankton growth (LaPointe, 1989).

2. Land and water use planning and development control

In order to reduce the risk from land-based sources of marine pollution, an ecosystems approach to coral reef system management will require that all sources of pollution -- from surface waters, groundwater, and the air -- be brought under control and strict management. Pollutants migrate between terrestrial and marine ecosystems, aided by several physical processes including coastal currents, air flow, and the gravitational and capillary flow of surface and subsurface waters. It has been shown that the reef system thrives under relatively narrow tolerance limits for several water quality parameters. The natural range of variation of such parameters can only be maintained if the cumulative impacts from coastal developments are given due regard in the land use planning, permitting, and follow-up monitoring and enforcement process. A list of recommended studies for inclusion in future Environmental Assessment Reports that may affect coral reef resources has been prepared by Dr. C. Rogers (formerly a DPNR staff scientist), and is contained in Teytaud (1980b). The list should be consulted by permitting officials during the scoping phase of all proposed major development projects.

Natural Hazards Mitigation

There is a need in the Territory for an effective coastal storm hazard mitigation policy and plan. The siting of facilities along the coast increases a the cumulative threat potential with respect to three types of coastal storm impacts: (1) threats to public health, safety, and welfare; (2) costs to tax payers for disaster relief and protection; and (3) losses of irreplaceable natural resources (Godschalk, *et al.*, 1989). Compounding the potential for catastrophic losses due to coastal storms is the possibility of significant sea level rise (SLR) in the decades ahead.

While average SLR over the last century has been less than one-foot (10-15 cm), an increase in that much or more (10-20 cm) is projected by 2025, and of between 1.5 and 6.5 feet (50-200 cm) by the year 2100. Using an average of 1 meter of shoreline erosion per cm of SLR, the resulting average by

2025 would be 33 to 66 feet (10-20 meters) [Godschalk, *et al.*, 1989].

There are generally three strategies that may be adopted to mitigate coastal storm hazards and SLR impacts. First, the natural coastline can be "hardened" by using designed protective structures, such as bulkheads, revetments, gabions, etc. Second, facilities and structures built in high hazard areas can also be hardened through the use of stricter building standards to achieve increased wind and/or flooding resistance. These strategies often require resorting to and preparing for evacuation of people during a storm event, with its incumbent risk to human life.

Third, and a better approach, coastal development can be redirected away from low-lying high hazard areas through the use of shoreline setback standards and/or re-zoning of high hazard areas to achieve simultaneous risk reduction and other objectives such as open space preservation or wildlife management.

This so-called "development management" strategy, is generally the most cost-effective option. As with the use of stricter building codes, increased costs associated with the alteration of land use patterns to reduce the exposure of people and property to storm damage are generally offset by long-term savings (from less damage) and reduced insurance rates. It is always (politically) easier to add a hazard mitigation section to an existing plan, regulation, or program than it is to adopt a totally new set of tools. In fact, there is no better time than today to prepare for the next storm, by introducing legislation that will require the use of new guidelines for decision-making during the next re-building effort.

A coastal storm hazard mitigation policy and regulations should be developed for the Territory. A "development management" alternative to hazard mitigation is recommended, and will require that implementing legislation be enacted soon in preparation for the next disaster. Future public and private developments should be directed away from high hazard areas. For existing development, policies and regulations should be considered that can be implemented now to minimize losses during the next storm. Finally, there should be established now (i.e., prior to its need) a plan to guide reconstruction following the next storm so that design and siting mistakes are not repeated.

*Moreover, proposed developments within the Coastal Barrier Resources System should be required to pass a strict "public need" criteria test, and approved **only** if no alternative site for the same use can be found.*

As seen above (section 2.3.2), earthquake potential in the Territory is high. Slopes on lands adjacent to the APC are considerable, while portions of coastal development adjacent to the APC sit on man-made fill.

Appropriate attention should be paid in the design of major facilities, especially those which will house large assemblies of people, so that threats of subsidence from seismic activity in filled coastal areas are absolutely minimized.

Although the liquefaction potential of landfill soils has not been determined for any landfills in the

Territory, logic suggests that certain compaction standards be adhered to and a certified engineer's report required for all major facilities.

Seismic hazards should be incorporated into subdivision regulations, with strict controls on development in high hazard areas.

Flooding mitigation will be an ongoing concern for new developments in many watersheds that discharge into the APC. Greater attention should be given to the cumulative impacts from developments associated with increased flooding potential. Individual watershed management plans, including a stormwater management component, should be developed for ecologically sensitive or heavily developed watersheds, especially those which lie adjacent to coral reefs, seagrass beds, and/or mangroves. Technical assistance should be sought to develop an Index of Land-based Sources of Marine Pollution (LBSMP) for principal watersheds. Such information, when used in conjunction with pollution susceptibility indices for adjacent bays (Nichols and Kuo, 1979), would assist in prioritizing watershed management planning needs. Watershed management measures should be developed to restore or enhance pristine reef conditions based on biocriteria.

Proponents of future developments should be required to design site-specific stormwater management plans and demonstrate to permitting authorities that the new development will not add to existing rates or volumes of stormwater runoff. Retention of stormwater on-site to allow for increased infiltration to groundwater should be considered as the preferred strategy in most cases.

Strict adherence to National Flood Insurance Program (NFIP) policies and regulations is recommended, and new developments restricted where the hydrology and flooding potential of an area may adversely affect important wildlife habitat or other natural features. Channelization for flood control should be avoided wherever possible, and new developments directed away from floodplain hazard areas. Cumulative impacts from the increased use of non-porous surface materials should be assessed, and guidelines established for the use of "grassphalt" and other porous surface materials on access roads, parking lots, and other suitable areas.

In addition to the above efforts for flood mitigation, an update of the 1979 stormwater management study should be considered for priority watersheds. Regular maintenance of drainage systems, and an assessment of proper culvert sizing should be given priority.

Nonpoint source pollution is a significant contributor to the overall degradation of nearshore environments in the U.S. Virgin Islands (Tetra Tech, 1991c). Although the islands have no perennial streams or rivers, episodic events of intense rainfall deliver pulses of fresh water laden with sediments, nutrients, organic matter, and potentially toxic chemicals to nearshore receiving waters. Control of nonpoint source pollution may have significant positive effects on pristine and otherwise valuable marine habitat. DPNR/DCZM and DEP have recently (1992) initiated a nonpoint source pollution control program.

The following list of recommendations for nonpoint source pollution discharge control is adapted from Tetra Tech, Inc. (1991c) and USEPA (1990), and is offered as only general guidance for land and water use planning as it may affect the APC. Site-specific nonpoint source recommendations have been offered in the relevant Studies cited above (section 1.3).

1. *separate storm and sanitary sewers;*
2. *collect and treat Combined Sewer Overflows (CSO's), using infiltration trenches/basins or chemical or filtration treatment systems;*
3. *regulate land use practices and behaviors that contaminate stormwater (e.g., waste oil disposal, establishment of green or infiltration areas on a portion of developed property, establishment of impervious surface limits);*
4. *impose routine inspection and management requirements for on-site (septic tank) wastewater systems;*
5. *develop treatment options for stormwater (e.g., retention basins, grassy swales, vegetation buffers, artificial wetlands);*
6. *implement source control practices such as street sweeping;*
7. *implement soil conservation measures on all construction projects (e.g., vegetation buffer zones, retention basins, silt-curtains, diversion ditches, etc.)*; and, *establish performance standards to reduce the total area of non-porous surface materials used on access roads, driveways, and parking areas; encourage the use of permeable materials such as "grassphalt", gravel, or appropriate vegetation.*

Marina fueling and boat repair services in the APC must be designed, maintained, and operated to reduce the risk of accidental spill and to facilitate clean-up in the event of a spill. Design practices include as a minimum:

1. *design boat hull maintenance areas to minimize contaminant-laden runoff;*
2. *locate and design fueling station and maintenance areas so that spills can be contained in a limited area;*
3. *implement source control practices such as vacuuming of impervious areas; use of tarpaulins to collect paint chips, sandings, and paint drippings; and use of sanders with vacuum attachments to collect hull paint sandings;*
4. *design spill contingency plans; and*
5. *design areas to include appropriate spill containment equipment.*

Liquid materials (i.e., oil, solvents, antifreeze, paints, etc.) must be prevented from entering coastal waters. Appropriate storage, transfer, containment, and disposal facilities should be provided and maintained, and recycling of liquid materials (especially oil) should be encouraged. Possible practices to implement these goals include as a minimum:

1. *build curbs, berms, or other spill containment barriers around areas used for liquid material storage; store liquid materials in areas that are impervious to those materials;*
2. *separate containers for disposal of waste oil, waste gasoline, used antifreeze, and oil-contaminated water; diesel, kerosene, and mineral spirits containers should be clearly labeled;*

3. *marina patrons and employees should be directed as to proper disposal methods for these materials through signs, mailings, training, etc.*

The amount of fuel and oil from boat bilges and fuel tank air vents entering marina and coastal waters should be minimized. Practices to implement this goal include as a minimum:

1. *use the best available technology (BAT) on air vents or tank stems of fuel tanks to prevent fuel from overflowing through tank air vents and spilling into coastal waters; and*
2. *place oil-absorbing materials in bilge areas of all boats with inboard engines; check these once a year and replace as necessary; recycle, if possible, or dispose of properly.*

3. Marine Conservation Districts

A precautionary approach and safeguarding strategy for managing the coral reef system involves the establishment of a system of Marine Conservation Districts throughout the APC. As mentioned above (section 1.3), an extensive marine area encompassing the East End was proposed in the early 1980's as a National Marine Sanctuary (Figure 4). Although the designation fell through at the time, the V.I. Government should consider a request to the appropriate Federal agency (NOAA) to re-evaluate the idea. National Marine Sanctuary sites are comparable to land areas in the National Park system that provide for public use for educational, recreational, research, and other purposes, while protecting natural resources. The sites receive special management attention, and allow for the development of an overall management plan based on a balance between resource protection and sustainable resource use. Thus, certain types and levels of fishing, for example, would be allowable either throughout the sanctuary or in specially designated "use zones". The establishment of a National Marine Sanctuary, as previously proposed, could greatly assist the Territory to achieve management goals for the APC.

Currently, the only marine protected area within the APC is the Buck Island Reef National Monument (BIRNM), however, it provides for only limited resource protection. Fishing is allowed within the Monument outside the "Marine Garden" area. Unfortunately, allowable catch includes two (2) lobsters and two (2) conch per person per day, as well as no limit for finfish caught with hand-line or rod-and-reel. These restrictions are not sufficient to prevent stock depletion in the long-term given the intense use of the Monument, and it is highly recommended that the V.I. Government work together with the National Park Service to have these regulations amended. It is recommended that all fishing be banned within Monument waters. [Note: The fishing regulations for BIRNM are included in the federal enabling legislation for the Monument, and thus any changes to them would require action by the U.S. Congress, a difficult, but not impossible, process.]

In addition to the need for specially managed areas within the APC where allowable uses are identified, there is the need for the establishment of "strict reserve" areas (commonly known as Marine Fishery Reserves, where all forms of fishing are banned). Such reserve areas would provide the following needed functions:

1. maintain species diversity;

2. protect critical breeding and nursery habitat;
3. protect stocks of large, mature, and highly fecund fish and other reef-associated species;
4. ensure a steady supply of propagules (eggs, larvae, and juveniles) for adjacent and down current reef areas; and
5. offer protection against failed fishery management attempts elsewhere (by providing full protection for resident fish stocks within a reserve).

Recognizing that episodic destruction, replenishment, and regrowth is a natural cycle for reef systems, the establishment of non-consumptive (i.e., strict reserve) areas is thus an important management goal for the APC. Marine Conservation District planning requires as a minimum the following (Salm, 1984):

a. the inclusion (as core protected areas) of all representative reef types and communities (species assemblages) found within the APC;
b. the inclusion of neighboring habitats (especially seagrass beds and mangroves) that are linked to selected core protected areas; and
c. the inclusion (either in boundaries or as part of planning areas) of contiguous coastal watersheds, and oceanic and atmospheric corridors which may impart significant impacts on core protected areas.

The following specific management objectives are proposed for the APC:

1. DPNR should initiate coordination with relevant governmental and nongovernmental entities to establish a marine conservation district system. DPNR/DFW and DCZM should undertake initial planning efforts, based on current and projected use of the marine environment by people, to determine priority marine protected areas within the APC and management objectives for each area. For example, some reefs should be managed for tourism and recreation, others for specific fishery management objectives, others for their scientific and ecological significance, and others as "multiple-use zones" where a combination of uses, compatible with long-term protection of the reef ecosystem, are permitted. It should be recognized that different types of reefs are more compatible for a given use than are other types. The establishment of various use zones achieves protection for core areas, separation of incompatible activities, monitoring of the impact of permissible activities, and maximum efficiency in the deployment of management equipment and the use of funds and personnel (Salm, 1984).

2. Reconsider putting forth a request to the Federal Government to designate a "St. Croix National Marine Sanctuary" for the East End. Combining federal and territorial talent and resources to manage this significantly large part of the coral reef system may represent the best opportunity for resource protection to be achieved in the short-term and sustained over the long-term.

3. Move to establish, as part of the territorial marine park system, an expanded protected

area around the Buck Island Reef National Monument (Figure 4), to provide increased protection to the coral and fishery resources of the Monument. It is recommended that all forms of fishing be prohibited within the core and expanded area. Where separate or overlapping jurisdictions exist, DPNR should work to obtain Memoranda of Agreements (e.g., with the National Park Service) which would specify resource management goals, objectives, standard protocol, and agency responsibilities.

4. Work with the Fisheries Advisory Committee of St. Croix to identify a combination of "strict reserve" areas (Marine Fishery Reserves) and "seasonally closed" areas. All forms of fishing would be prohibited year-round at the former sites, while the latter sites would be identified and established to provide protection during seasonal spawning aggregations. [Note: DPNR/DFW, in conjunction with the Caribbean Fisheries Management Council, has recently established seasonal closures for a Red Hind spawning area on Lang Bank (Figure 4), and a Mutton Snapper spawning area off the southwest coast of St. Croix. These closures are located within federal waters and are promulgated under the authority of the Magnuson Fisheries Management Act. USCG and/or NMFS vessels and personnel will be used to monitor and enforce the seasonal closures (pers. comm., W. Tobias, DPNR/DFW).

5. Focus on building the constituency -- the base of private, public, political, and financial support -- for the establishment of a marine protected areas system. Representatives of both the fishing and tourism industries must be involved in all phases of planning and development.

6. Develop ways to reduce stress on the coral reef system due to fishing pressure by continuing to develop or enhance alternative fishing methods and target species. In this regard, funds will be needed for construction and deployment of Fish Aggregating Devices (FADs), construction of artificial reefs, and other habitat enhancement projects including those for larval recruitment. The goal is to relieve fishing pressure from inshore stocks, and target underutilized species, such as the seasonally abundant pelagic fishes which can be caught within reasonable range offshore.

4. Coral reef fishery management

Management objectives for a coral reef fishery must be based on an understanding of general reef ecology and the degree by which a reef fishery is susceptible to overexploitation. As seen above (sections 2.4.1 and 2.4.4), preferred species of coral reef fish (e.g., snappers and groupers) can be overharvested easily, even by subsistence fishing, because of their irregular recruitment, slow growth, longevity, and low rates of population turnover. Moreover, the dramatic decline of a single reef species can result in a "domino effect" of changes throughout the coral reef ecosystem. Most notably of such changes is the well documented increase in benthic algae which can rapidly overcome a healthy reef when its stock of grazing fishes is severely depleted.

A common feature of coral reef fisheries, especially in the Caribbean where reef tenureship is rarely found, is the potential "tragedy of the commons", whereby individual fishermen work to maximize their own catches, while thinking that if they do not catch the fish then others will. Such a situation of intense fishing competition is described for the Bermuda fishery by Butler, *et al.* (1993). In Bermuda, as a percentage of total catch, groupers declined from 70 percent in the late 1950's to 19 percent in 1989. After the large, predatory reef fish were overfished, fishing effort was next targeted at herbivorous reef fish. During the same 30 year period, miscellaneous reef fishes such as parrotfish, surgeonfish, porgy, grunt, triggerfish, hogfish, and Bermuda chub increased from less than 1 percent to 31 percent of total catch. This dramatic increased pressure on herbivorous fishes, coupled with the region-wide mass mortality of *Diadema* in 1983, was cause for great concern for the integrity of Bermuda's coral reef ecosystem (Butler, *et al.*, 1993). The various types and degrees of fisheries management responses made by government officials in Bermuda, leading finally to the complete ban on the use of fish pots (traps), is an interesting and illustrative case study in coral reef fishery management.

Management of the coral reef fishery on St. Croix will necessitate a similar recognition that the coral reef system is *not* highly productive in terms of fish biomass, and that strict controls on allowable fishing techniques and gear types will be necessary to prevent a collapse of fish stocks. Moreover, the same resource that supports the fishermen, also supports tourism and recreation, including commercial ventures involved with charter-boat fishing, SCUBA diving, snorkeling, and glass-bottom boat tours. The success of these enterprises depends on clear waters, interesting reef topography, and live, healthy reefs with many brightly colored reef fishes to observe. Thus, a first realization for coral reef fishery management is that certain trade-offs with other user groups will be necessary. In Bermuda, the recognition of the multi-user aspect of the reef system lead to an inferred policy statement for fishery management: "The aesthetic and recreational value of this environment, dominated by coral reefs, is inestimable. The loss of any part of this magnificent resource would be catastrophic and the costs of any attempt at replacement would be staggering. The importance to Bermudians of being able to obtain fresh fish cannot be overemphasized, nor can the importance of fresh fish in restaurants and hotels be discounted in the tourist industry." (Butler, *et al.*, 1993). A similar policy should be developed and utilized to promote consensus for coral reef fishery management goals within the APC.

The following specific fishery management objectives are offered for the St. Croix Coral Reef System APC:

1. The fishery harvest shall be controlled by whatever combination of methods is necessary to ensure that the ecological integrity of the coral reef system is preserved. This policy position recognizes the inherent vulnerability of reef fisheries to overexploitation and the catastrophic effects that may result from a single species decline.

2. Commercial fishing in the APC shall be by special license only.

3. Certain gear types shall be prohibited. The use of gill nets, SCUBA gear for fishing, and spearfishing shall be prohibited.

4. The use of fish traps (pots) should be evaluated for their cumulative impacts to the reef system, and their use prohibited or highly restricted if found to be not compatible

with fishery management goals. Regulations regarding the use of fish traps should be re-evaluated and refined, including:

a. Minimum mesh size of 2" shall be established.
b. All fish traps shall be required to have "escape panels" secured with 1/8" untreated jute twine.
c. In consultation with the local fishermen, DPNR shall establish an overall quota of traps and a maximum allowable total per fisherman in the APC;
d. Only commercial fishermen holding a permit for fishing in the APC shall be allowed to use fish traps (pots). Their use shall be prohibited for all recreational fishermen. It should be noted that the unregulated use of fish traps on Jamaican reefs over the past 20 years has virtually eliminated herbivorous fishes in some areas (La Pointe, 1989).

4. Fishing licenses shall be required of all fishermen, both commercial and recreational fishing in the APC.

5. A system of Marine Conservation Districts shall be established in the APC by DPNR in consultation with the St. Croix community. Due to its especially important ecological value, the nearshore area and bank-barrier reef system from Coakley Bay to Milford Point (East End) shall be identified as a strictly recreational fishing zone (pole-and-line only) with catch limits to be determined by DPNR in consultation with the recreational fishermen. Other "special management" zones should be established as the need and enforcement capability evolves.

6. Currently, only one commercial business is licensed on St. Croix to remove reef fishes for the aquaria trade. It is recommended that no additional licenses be granted for collection of aquaria fish or reef-associated species.

7. Cooperative efforts on fisheries management with other governments within the Wider Caribbean should continue (e.g., harmonized fisheries legislation) to ensure that adequate shared fish stocks are maintained and managed throughout the range of the stock.

8. The Nassau Grouper (*Epinephelus striatus*), formerly a major component of the commercial fish catch both in the Virgin Islands and on the mainland, is now considered fishery extinct and is being discussed as a candidate for protection under the US Endangered Species Act. It is imperative that this species be protected. Therefore, it shall be prohibited to deliberately catch or possess Nassau Grouper within the APC.

5. Visitor/recreational use impacts

Visitor and local recreational use of the St. Croix Coral Reef System APC can be expected to continue to increase in the years ahead. The Buck Island Reef National Monument alone attracts 50,000 visitors per year, of which 90 percent visit the underwater snorkeling trail (Wells, 1988). And for the first six months of 1993, the visitor count stood at 35,000, an indication of a significant annual increase for the current year (pers. comm., W. Cissel, National Park Service). Heavy recreational diving use of the coral reefs at Cane Bay, Salt River Bay, and Green Cay National Wildlife Refuge are also reported (pers. comm., Z. Hillis, National Park Service). Similarly, the V.I. National Park on St. John has experienced phenomenal growth in visitor and recreational use of the Park's reefs, and significant (cumulative) adverse impacts have been observed and recorded over a number of years, including impacts of the following type (Marion and Rogers, 1992):

1. physical damage to reef structures (boat groundings, anchor damage, reef-walking, etc);
2. harassment of marine animals;
3. artificial feeding of reef organisms;
4. collection of reef organisms; and
5. pollution of reef waters from boat oil and gas residues.

the control of visitor/recreational use impacts can be accomplished by a combination of several methods, but will require a dedicated effort by a responsible and accountable entity to ensure that management goals are implemented and enforced. At the present time, DPNR/DEE is the environmental enforcement entity of the V.I. Government for both marine and terrestrial regulations, and thus the likely responsible agency to become involved with daily monitoring and enforcement of additional regulations. It should be understood, however, that education must play a large role to assist in minimizing such impacts, and thus a cooperative effort with the general public and marine-related businesses will most likely bring about the best results in minimizing visitor and recreational impacts. For example, it is common elsewhere for the operators of SCUBA dive businesses to deliver a pre-dive talk on environmental protocol for the underwater environment.

A combination of the following management strategies should be employed to minimize visitor impacts (Marion and Rogers, 1992):

1. <u>Restrict high-impact uses</u>. Large boats and large groups of people, for example, tend to result in more frequent and more significant adverse impacts to reefs. The National Park Service has thus prohibited boats greater than 69 m (226 ft) long from entering Park waters. At the same time, a system of low-impact anchorages (permanent moorings) has been established. Larger groups can make it more difficult to deliver effective talks on environmental protocol.

2. <u>Contain rather than disperse recreational use</u>. Use containment seeks to minimize impacts through the intensive use and management of areas selected for their impact resistance and resiliency. Such is the idea behind underwater snorkeling trails that are designed to attract a large percentage of the total number of visitors. Visitor impacts can be more easily controlled in this manner. Such areas should be strategically located near adequate shore-based facilities. Marine area zoning (e.g., "no-boating", "no-anchoring", "no jet skis", etc.) should be established for especially vulnerable seagrass beds and coral reef communities.

3. Encourage the use of resistant environments. It has been found, for example, that certain coral species display differential resistance to trampling. Coral reef communities in the reef crest zone were at least 16 times more resistant to trampling damage than communities in the outer reef flat zone (Marion and Rogers, 1992). Further research and monitoring is needed, but the "zoning" of reef communities for different allowable uses should be an ongoing component of reef management efforts.

4. Teach low-impact recreational practices. First-time SCUBA divers and snorkelers to the tropical coral reef environment may not appreciate how delicate and vulnerable certain species really are. A "look but don't touch" educational program is thus needed for certain especially sensitive areas. Some national marine sanctuaries in the U.S. make it illegal to stand on or touch the coral.

5. Enforce park (or APC) rules and regulations.

6. Document resource use. Start by collecting diver frequency and impact information on a site-by-site basis. Require that diver operations participate in this effort, and establish a database of information within DPNR/DFW or DPNR/DCZM.

The St. Croix diving community has undertaken several initiatives on its own that support the above management measures, including the installation and maintenance of at least 20 permanent moorings around the island. The nonprofit organization, Anchors Away, has been responsible for the latter initiative (although it has been recently reported that the lack of mooring maintenance has rendered all of the moorings unusable). Such public involvement needs to be recognized, encouraged, and appropriately supported with public funds. A coral reef protection fund, or its equivalent, should be established for this purpose, to provide stability and longevity to such efforts (section 4.3).

6. Long-term monitoring

For the longer-term, an ecological monitoring program, including a fully functional and goal-oriented water quality monitoring program, will greatly facilitate the reef system management effort. Environmental crises develop faster than they are often noticed through casual observation. An orderly regime of ecological monitoring, if well-designed and implemented, will allow detection of more subtle, secular disturbance to the chemical, biological, and physical condition of the reef system. And although there are many considerations to be made in the design of a monitoring program, it is more important to get started immediately on a well conceptualized schedule of observations and measurements, than it is to wait for the funds and/or personnel to carry out a more elaborate, comprehensive program.

A long-term ecological monitoring program for the Coral Reef System APC should be simple, practical, reliable, and replicable by a wide number of trained personnel. It should select less time-consuming monitoring techniques (e.g., visually assessed quadrats), over more time-consuming (e.g., fixed chain transects) or expensive techniques that may provide only a marginal improvement in accuracy (Bythell, *et al.*, 1992). The monitoring program should focus on repeat sampling of the same population(s), rather than on random surveys. Thus, the use of global positioning system (GPS) equipment is highly recommended. Monitoring should also be designed to be free from observer bias.

Basic elements of a long-term ecological monitoring program for the reef system include:

1. long-term, year-round monitoring at selected sites;
2. well defined goals based on good science;
3. goals that are linked closely with management goals;
4. adequate funding;
5. monitoring program designed to provide early warning of degradation;
6. monitoring program designed to help develop an understanding of the natural processes and variability involved in the system, and to predict the effects of human activities on ecological processes.

A monitoring program for the APC should assess (as adapted from Gjerde and Fujita, 1992; and Rogers, 1992):

1. physical damage due to fish harvesting, ship groundings, coral collecting (although this activity is illegal), diver and snorkeler damage, etc.;
2. trends in water quality (including salinity, dissolved oxygen, conductivity, Ph, temperature, turbidity and nutrients such as nitrates and phosphates), as well as trends in the accumulation of toxic compounds in marine biota and sediments;
3. sources of pollution (terrestrial and marine, local and regional), including both point and nonpoint sources;
4. status and trends (e.g., percent live coral; spatial complexity; presence of disease, etc.) of populations of reef-associated species; and
5. other environmental parameters, including ultra-violet light variability, sedimentation, eutrophication, sea level change, etc.

Given personnel and budgetary constraints, not all of the above named water quality monitoring parameters will be priority for the St. Croix reef system. Moreover, certain measurements may be taken at different temporal and spatial scales as appropriate. In general, water quality sampling sites should include both pristine and degraded waters, the former to keep track of changes in these waters and provide reference sites for comparison with degraded waters. Degraded waters will generally be located downslope and/or down current of intensively developed watersheds, significant coastal developments, or near other known pollutant sources such as ports, marinas, or outfalls. Given the relatively good mixing of St. Croix's coastal waters, salinity, Ph, and conductivity are not likely to fluctuate much between sites and years, and should be given a lower priority if faced with budget limitations. Dissolved oxygen, turbidity, nutrients (nitrates, nitrites, phosphates, and ammonia), and bacteria (especially, fecal coliform) should be given a greater relative priority.

DPNR should convene a meeting (or a series of meetings) of all relevant governmental and non-governmental entities to discuss a coral reef monitoring strategy. The meeting should consider the need to formally establish a Coral Reef Monitoring Committee, whose role would be to establish goals, schedules, protocol, responsibilities, and sources of funding for the long-term effort. Various V.I. Government entities should be represented (i.e., DPNR, DPW, WAPA, and Port Authority), as well as the relevant Federal agencies (i.e., NPS and USFWS), the University of the Virgin Islands, relevant non-governmental groups, the Fisheries Advisory Committee, and interested citizens. The Committee should be a truly pluralistic representation of the community, but one which will be able to receive and account for public and/or donated funds.

Moreover, regular training of all personnel, the development of calibration techniques for monitoring equipment, and the standardization of procedures and scientific protocol to be used, are essential. Several good references are available regarding coral reef monitoring techniques and sampling protocol; see for example, Kenchington and Hudson (1984) and Rogers (1993, in press).

7. Local capacity for coral reef management

Long-term success of coral reef management efforts will be determined in large part by the ability of select government personnel to design, implement, and maintain a coral reef management strategy. Technical, managerial, and organizational capability will be needed to ensure that all technical aspects and administrative support mechanisms are in place to sustain a management program, including heavy commitments to monitoring, enforcement, and public education. Several technical personnel must be trained in standardized protocol for reef monitoring, and a team approach developed to ensure that the various management objectives described herein are given simultaneous attention. It will be difficult, if not impossible, for these recommended management measures to be undertaken for the entire APC given the mix of resources (human and financial) currently available within any single V.I. Government agency. It is recommended that a lead agency in DPNR be designated to establish a long-term ecological monitoring plan for the coral reef system, initiate memoranda of agreements or other protocol with the relevant departmental divisions (i.e., DFW, DEP, DCZM, and DEE), with the Environmental Research Section of the Eastern Caribbean Center and the Department of Marine Biology at the University of the Virgin Islands, and with the relevant federal agencies (i.e., USFWS, NPS, etc.) on specific aspects of the overall strategy. Moreover, perhaps there is valuable assistance to be obtained from federal agencies to assist in the development of local capacity for coral reef management.

8. Public awareness and support

Clearly, management efforts for the coral reef system must involve local communities. The efforts by Anchors Away to install (if not adequately maintain) moorings around the island have been already mentioned as an example of how the nongovernmental sector can contribute to management goals. Perhaps this or another group could work to monitor compliance with Annex V of MARPOL by retrieving, identifying, and tabulating amounts of plastic marine debris. In addition to its immediate public educational value, such information may serve to stimulate future regional discussions on the effectiveness of MARPOL regulations. The objective is to instill a sense of community stewardship for the reef system, and to foster constructive dialogue on the suggested policy framework and management goals. The importance of public participation and sufficient levels of support funding for volunteer efforts should not be underestimated. Such activities as volunteer clean-ups and sport diver reef monitoring programs will require funds which might ideally be channeled to environmental groups, recreational clubs, and other community groups for sponsorship.

9. Cultural resources

The DPNR/Division of Archaeology and Historic Preservation is responsible for oversight of historic preservation in the Territory and for protection of the Territory's historic and archaeological resources (collectively known as cultural resources). The division carries out a number of specific duties mandated by the National Historic Preservation Act of 1966 (P.L. 89-665).

These duties include maintaining an inventory of historic and archaeological sites within the Virgin Islands, testing and evaluating such resources, and nominating significant resources to the National Register of Historic Places. Presently, most sites on the Virgin Islands inventory have been only superficially examined and/or partially tested. The submerged cultural sites within the APC have received only minimal attention and have never been subject to a systematic, comprehensive magnetometer survey. The survey and evaluation of sites is an ongoing process and consideration of impacts on known sites, by itself, is not adequate to fully protect the Virgin Islands' significant cultural resources, both known and unknown.

Under Section 106 of the National Historic Preservation Act, the DAHP is responsible for protection of historic shipwrecks and other significant underwater cultural resources, including historic artifact concentrations, prehistoric sites, submerged historic structures, and other evidence of former land and marine activities. DAHP has promulgated standards and guidelines for the conduct of cultural resource investigations which must be followed as part of the permitting process for proposed activities. In addition, the Commissioner of DPNR has issued a Public Notice regarding the fact that cultural resources located within submerged lands are held in trust for the people of the Virgin Islands, and that any conduct of investigations requires the prior approval of the DPNR (USVI Govt/DPNR, n.d.). These guidelines and requirements should be generally sufficient to guide the development control process, but additional attention to monitoring and enforcement will be needed to prevent further degradation of cultural resources throughout the APC. There is, however, still a great need for passage of antiquities legislation in the Territory (section 4.3).

10. Regional and international efforts

For successful management of the St. Croix Coral Reef System it is important to understand the international implications of coastal and marine resource management. The Caribbean is a geographically small area, and the pattern of oceanographic currents allows for quick and widespread dispersal of marine pollutants and disease. The spread (from Panama to the Bahamas) of a water-borne pathogen, thought to be responsible for the 1983 mass mortality of the long-spined sea urchin, *Diadema antillarum,* was completed within a year. Likewise, suspended particulates and other pollutants are carried through the Caribbean by currents from distant sources, including terrestrial runoff from major rivers along the South American coast. Oil spills in one country can easily affect countries down-current. Larval recruitment to the St. Croix reef by different marine species (e.g., lobsters) is likely dependent on survival rates of larvae arriving from upcurrent areas.

The V.I. Government should, through proper channels, encourage U.S. Government support for a number of regional and international protocols calling for increased protection of the environment. Among such efforts, it should support the protection of coral reefs throughout the region under the protection of the Specially Protected Areas and Wildlife (SPAW) protocol of the Cartagena Convention (U.S. ratified). It should also move to support inclusion of selected, slower-growing or "precious" corals (e.g., Antipatharians) under the Convention on the International Trade of Endangered Species of Wild Flora and Fauna (CITES). Moreover, the development of integrated coastal zone management programs throughout the region should be seen as in the best interest of protecting the overall health and productivity of the Caribbean Sea, and thus a long-term management goal for ensuring the maintenance of water quality and supplies of healthy propagules.

SITE-SPECIFIC RECOMMENDATIONS

Davis Beach to Salt River Canyon

The bottom reefs off Davis Bay are today stressed by heavy sediment load. Poor land use planning and sediment control practices for a major resort development in the adjacent watershed is the major contributing factor. An increased monitoring and enforcement presence is needed on such large, potentially destructive coastal developments.

Further to the east, Cane Bay is a popular dive site with its precipitously sloped, narrow fringing reef. The reef was heavily impacted by Hurricane Hugo and has not fully recovered. Heavy use by sport divers and snorkelers has placed the reef under increasing stress, and it is extremely doubtful that the area can sustain such intense use. The situation calls for a current usage survey, survey of the reef community, assessment of impacts to the reef, and the development (with participation by all interested parties) of use limitations, if required. Cane Bay is a good example of why the diving community must be organized to become involved in self-management of its industry, if destruction of the industry's central attraction is to be avoided.

Protection of the reef at Salt River Bay is discussed in the Study for Salt River Bay APC. The Salt River Park Commission should move quickly to offer resource protection to the entire estuary and offshore waters (including the submarine canyon). The Salt River submarine canyon and adjacent reefs represent a national and territorial treasure for the baseline information on various natural resources which exists as the result of 13 years or more of NOAA-sponsored research efforts. DPNR should compile and reassess the baseline information, and establish a course of action to ensure that critically important monitoring continues.

Long Reef

The preservation of Long Reef as a valuable "marine outdoor classroom" for St. Croix residents is discussed in the Study for the Christiansted Waterfront APC. Other management recommendations regarding water quality are offered in the plan as well. Long Reef is an important component of the entire marine ecosystem both within and adjacent to Christiansted Harbor. The reef should be formally designated as a Significant Natural Area and/or a marine reserve site.

Scotch Bank

The area southwest of Buck Island Reef National Monument is a shallow, sloping bank area. Prior to

Hurricane Hugo, the bank was a habitat rich in sponges and gorgonians. It is an ecologically sensitive area deserving of special management attention, including an assessment of fishing pressures in the area.

Buck Island Reef National Monument

As mentioned previously, although the BIRNM is afforded certain resource protection, commercial fishermen are allowed to fish within Monument waters. If consensus and support could be reached with commercial fishermen, the area would make an ideal marine fishery reserve to provide habitat and protection for mature, fecund reef fish. An expanded area, within which fishing would be prohibited, would be most useful in this regard (Figure 4). DPNR/DFW, in conjunction with the National Park Service, should discuss this and other marine protected area options with the Fisheries Advisory Council of St. Croix.

Tague Bay Reef/East End bank-barrier reef

The former West Indies Laboratory was located on the shore of Tague Bay, and many reef monitoring and research studies were carried out in the area during the course of over 20 years (Figure 6). Thus, like the Salt River canyon and reef area, the Tague Bay Reef and bank-barrier reef to the east is a scientifically important component of the reef system. It should be given special management attention to safeguard its value as habitat, research, and its general contribution to shoreline protection for the heavily built coastline (pers. comm., Z. Hillis, National Park Service).

Southeastern reef

Adey, *et al.* (1981) recommended that this area be kept in a natural, pristine state for its high ecological and research value. The area has been the subject of fairly extensive coral reef research. Only limited (i.e., controlled) use of the reef area by island residents should be allowed. This includes limitations on fishing. The area offers good examples of algal ridges at several places along the coast (Figure 6) and, together with relatively pristine and diverse terrestrial habitat, represents one of St. Croix's best candidates for inclusion in the Territorial Park System (USVI Govt/DPNR, 1991). As such, and for other reasons, the proposed 108-unit subdivision at Jack Bay and Isaac Bay should be permitted only if all adverse impacts from this development can be mitigated. As proposed, adverse impacts from the development will be difficult to mitigate. Most of the area is extremely steep (40-60 percent slopes) and of loose, highly erodible (Cramer series) soils. Effective and environmentally benign sewage treatment under such conditions is difficult to accomplish. Moreover, terrestrial runoff laden with sediments, nutrients, and chemicals (e.g., pesticides) would be difficult to avoid. Such impacts would severely degrade the adjacent reef system. Both bays are utilized by sea turtles for nesting, and for foraging among the seagrass beds and nearshore reefs (pers. comm., Z. Hillis, National Park Service). Even with the existing level of development, disturbance to nesting sea turtles has been reported.

4.3 Legislative Change

Apparently missing from current law is wording which recognizes and provides particular support of the need for an ecosystems approach to coral reef system management. Such legislation could: (1) designate within DPNR the appropriate division to play the lead role in coral reef management throughout the Territory; (2) provide a legislated policy framework that would support the future promulgation of regulations pertaining to specific aspects of coral reef system management; and (3) provide special funding for the establishment of a management program that will have many long-term funding needs. Without such legislated mandate and funding support, it is difficult to see how current (already stretched) resource management budgets will provide for program development, including the essential implementation of long-term ecological monitoring.

Title 12, Chapter 7, entitled "Water Pollution Control", provides a description of "best usage of waters" and the water quality standards that must be met to maintain designated uses. As mentioned previously (section 4.2), the Territory should consider adding to this Chapter a new designation called "Outstanding National Resource Waters (ONRW)", which would allow for special recognition of the St. Croix Coral Reef System as a national and territorial treasure deserving of special efforts to maintain and enhance water quality. Specific recommendations in this regard, as well as specific recommendations for changes to the water quality standards, were offered above (section 4.2).

In addition, there is need for legislative action to consolidate all existing floodplain management regulations under a single Floodplain Development Ordinance. Carried further, such an ordinance should be ideally incorporated into a larger Coastal Growth Management Ordinance, which speaks to the long-term need to control growth and redevelopment in all high hazard areas.

There is no V.I. law regarding the use of jet skis. Although they are considered to be motor vessels, there are no standards (noise, speed, etc.) by which they operate, and no specific provisions in the law to consider the needs of other water users, including swimmers and various aquatic or wildlife species. The use of jet skis is not compatible with many other water uses, and thus requires perhaps both temporal and spatial control in the context of an overall plan or management strategy. This will require study and legislation since current law does not permit discrimination against "jet ski" or similar watercraft.

The DPNR/DHAP is currently working on an Antiquities Legislation Bill that will be submitted to the legislature for approval. This will deal with future submerged treasure hunters. The Territory's cultural resources, including those submerged within the APC, are presently not adequately protected.

Finally, legislative action is needed to create something like a "Coral Reef Protection Trust Fund" which would allow for the collection of funds from various fees, penalties, sale of concession rights, etc, to be put directly toward coral reef system management. Certain incentives could be established at the same time to encourage donations from the wider community for this purpose.

4.4 Institutional Development

As mentioned previously, DPNR should initiate a series of meetings with relevant governmental and nongovernmental entities regarding the implementation of a coral reef management program. Coordination between DPNR divisions (e.g., DFW, DEP, DCZM, and DEE) will be necessary, as will coordination with other departments (e.g., DPW, WAPA, Port Authority) involved with land and water use. Successful management of the coral reef system will come about quicker and with more lasting results if the local community, including landowners in the more than 60 watersheds which abut the APC, are drawn into the planning process. This attempt has been initiated with the drafting of the APC Comprehensive Analytic Study and proposed management plan, and to this end DPNR has solicited input from various user groups, environmental organizations, and members of the business community. It is hoped that these groups will together and in conjunction with DPNR address certain specific components of the Study and proposed management plan, and even finance certain elements that will have obvious payback benefits to the entire community.

5. CONCLUSION

The St. Croix Coral Reef System APC is a territorial and national treasure of inestimable value. As one of the best developed reef systems in the Caribbean, and the most extensive coral reef system on the Puerto Rican-Virgin Islands shelf, its ecological, scientific, economic, educational, and recreational values cannot be overstated. The reef system, together with its adjacent seagrass beds and mangrove habitats, is central to the nutrient cycling that drives the entire marine ecosystem, while protecting shorelines from erosion and providing a source of valuable beach sand. In short, its continued health and productivity is essential for the maintenance of a high quality-of-life -- and cultural heritage -- for the island's residents.

Coral reefs worldwide are under increasing threat from a variety of natural and anthropogenic stresses. Should current predictions unfold, global climatic change, including the possibility of accelerated sea level rise and more frequent and severe hurricanes, will exert increasing stress on coral reefs during the next several decades. Together with man-induced stresses resulting from human activities at sea and both water-based and land-based sources of marine pollution, these increased stresses will become increasingly manifest by dramatic declines in live coral coverage and overall health of reef systems in many places throughout the world.

In the relatively small and oceanographically connected marine environment of the Caribbean, water-borne pollutants and disease agents can be spread quickly. This was witnessed several times during the past decade with the spread of coral diseases and a pathogen which attacked the ecologically important sea urchin *(Diadema antillarum)*. Thus, coral reef management efforts must focus not only on local management measures, but also on international efforts of integrated coastal zone management. Fundamental to the latter effort is an understanding that not only is preventing the spread of disease- or pollutant-contaminated water an important goal, but likewise important is the maintenance of healthy and abundant stocks of propagules (eggs, larvae, or juveniles) for "re-seeding" adjacent and down current reef systems.

Notwithstanding the above, local management measures for the St. Croix reef system are the focus of this Study and proposed management plan. Section 2.4.4 discusses the range of man-induced stresses and the ecological responses they elicit. Among these, one of the largest stressors and of growing concern is that of terrestrial stormwater runoff, and the sediments, chemicals, and nutrients that such runoff discharges to the marine environment. Also in need of management attention are adverse impacts arising from visitor/recreational use, fisheries, and point source discharges such as from sewage and industrial outfalls. The policy framework proposed in Section 4.1 recommends a precautionary approach in controlling impacts from these and other human activities, recognizing that the synergistic effects of changes to the chemical, physical, and biological integrity of the reef system are presently poorly understood. In this regard, a system of marine protected areas, coupled with stricter standards which will maintain water quality at or near its natural, pristine condition, is a recommended component of a long-term management strategy.

DPNR should to ensure that effective management of the reef system occurs by working to establish a broad-base of support for and participation in the management activities described herein. A first step is to convene a series of meetings between relevant nongovernmental, territorial, and federal entities who might have a role to play in the design and implementation of a coral reef monitoring program. Local capacity building, public support and involvement, and key legislative change are all required to bring the Territory's full complement of human, financial, and legal resources to bear on the task of achieving a successful, long-term management plan for the St. Croix Coral Reef System.

REFERENCES CITED

Adey, W.H., 1975. The algal ridges and coral reefs of St. Croix: Their structure and Holocene development. *Atoll Res. Bull.* 187:67 pp.

Adey, W.H. and P.J. Adey, 1979. Definition and general discussion of reef zones. *In* BC&E/CH_2M Hill, 1979. A sediment reduction program. Prepared for the USVI Government, Department of Conservation and Cultural Affairs. Gainesville, FL.

Adey, W.H. and R. Burke, 1976. Holocene bioherms (algal ridges and bank-barrier reefs) of the eastern Caribbean. *Geological Society of America Bulletin.* 87:95-109.

Adey, W.H., W. Gladfelter, J. Ogden and R. Dill, 1977. Field guidebook to the reefs and reef communities of St. Croix, Virgin Islands. Third International Symposium on Coral Reefs. The Atlantic Reef Committee, University of Miami. Miami Beach, FL.

Adey, W.H., C.S. Rogers, R.S. Steneck and N.H. Salesky, 1981. The South St. Croix reef system: A study of reef metabolism as relates to environmental factors and an assessment of environmental management. Prepared for the USVI Government, Department of Conservation and Cultural Affairs, by West Indies Laboratory. St. Croix, USVI.

Allen, W.H., 1992. Increased dangers to Caribbean marine ecosystems. *BioScience* 42:5.

Anderson, M., H. Lund, E. Gladfelter, and M. Davis, 1986. Ecological community type maps and biological community descriptions for Buck Island Reef National Monument and proposed marine sites in the British Virgin Islands. Virgin Islands Resource Management Cooperative: Biosphere Reserve Research Report No. 4. Virgin Islands National Park.

BC&E/CH_2M Hill, 1979. A sediment reduction program. Prepared for the Government of the U.S. Virgin Islands. Gainesville, FL.

Birkeland, C., 1990. Caribbean and Pacific coastal marine systems: Similarities and differences. Unesco publication *Nature and Resources.* 26(2).

Bowden, M.J., 1968. Water balance of a dry island: The hydroclimatology of St. Croix Virgin Islands and potential for agriculture and urban growth. Geography Publications at Dartmouth, No. 6. Clark University, Worcestor, MA.

Bowden, M.J., 1970. Climate, water balance, and climatic change in the northwest Virgin Islands. Published under the auspices of the Caribbean Research Institute, College of the Virgin Islands. St. Thomas, USVI.

Bowden, M.J., 1974. Hurricanes in paradise: Perception and reality of the hurricane hazard in the Virgin Islands. Published by Island Resources Foundation. St. Thomas, USVI.

Brower, D.J. and T. Beatley, 1988. Natural hazard mitigation plan for the U.S. Virgin Islands. Prepared for the Virgin Islands Territorial Emergency Management Agency (VITEMA). St. Thomas, USVI.

Brown, B.E. and J.C. Ogden, 1993. Coral bleaching. *Scientific American.* January 1993.

Butler, J.N., 1993. The Bermuda fisheries: A tragedy of the commons averted? *Environment.* 35(1).

Bythell, J.C., M. Bythell, and E.H. Gladfelter, 1992. Coral reef community structure assessment based on planar and three-dimensional area cover: A comparison of techniques. *In* Ecological studies of Buck Island Reef National Monument, St. Croix, USVI: A quantitative assessment of selected components of the coral reef ecosystem and establishment of long-term monitoring sites. Part II. Prepared for the National Park Service. Published by Island Resources Foundation and West Indies Laboratory.

Bythell, J.C., E.H. Gladfelter, and M. Bythell, 1992. Ecological studies of Buck Island Reef National Monument, St. Croix, USVI: A quantitative assessment of selected components of the coral reef ecosystem and establishment of long-term monitoring sites. Part II. Prepared for the National Park Service. Published by Island Resources Foundation and West Indies Laboratory.

Bythell, J.E., W. Gladfelter, K. French and Z. Hillis, 1989. Buck Island Reef National Monument: Changes in modern reef-community structure since 1976. *In* D.K. Hubbard, ed., Terrestrial and Marine Geology of St. Croix, U.S. Virgin Islands. West Indies Laboratory. St. Croix, USVI.

Chelsea International Corporation, 1983. National marine sanctuary site evaluations: Recommendations and final reports. Prepared for the National Oceanic and Atmospheric Administration, Office of Ocean and Coastal Resource Management. Washington, D.C.

Coulston, M.L., 1987. Biomonitoring study of municipal sewage impacts on selected corals: Red Point sewage outfall, St. Thomas, U.S. Virgin Islands. Prepared by Island Resources Foundation. St. Thomas, USVI.

Davidson, L. and K. Gjerde. An evaluation of international protection offered to Caribbean coral reefs and associated ecosystems. Joint publication of Greenpeace International and the Marine Policy Center, Woods Hole Oceanographic Institution.

Davies, P.J., 1983. Reef growth. *In* Perspectives on Coral Reefs. D.J. Barnes (ed.). AIMS. Townsville, Australia.

Davis, M., E. Gladfelter, H. Lund and M. Anderson, 1986. Geographic range and research plan for monitoring white-band disease. Virgin Islands Resource Management Cooperative: Biosphere Reserve Research Report No. 6. Virgin Islands National Park.

Department of Planning and Natural Resources, Division of Coastal Zone Management, 1993a. U.S.

Virgin Islands, St. Croix, Christiansted Waterfront APC Comprehensive Analytic Study. USVI Government, St. Thomas, USVI.

Department of Planning and Natural Resources, Division of Coastal Zone Management, 1993b. U.S. Virgin Islands, St. Croix, East End APC Comprehensive Analytic Study. USVI Government, St. Thomas, USVI.

Department of Planning and Natural Resources, Division of Coastal Zone Management, 1993c. U.S. Virgin Islands, St. Croix, Great Pond Bay APC Comprehensive Analytic Study. USVI Government, St. Thomas, USVI.

Department of Planning and Natural Resources, Division of Coastal Zone Management, 1993d. U.S. Virgin Islands, St. Croix, Salt River Bay APC Comprehensive Analytic Study. USVI Government, St. Thomas, USVI.

Department of Planning and Natural Resources, Division of Coastal Zone Management, 1993e. U.S. Virgin Islands, St. Croix, Southgate Pond/Chenay Bay, APC Comprehensive Analytic Study. USVI Government, St. Thomas, USVI.

Department of Planning and Natural Resources, Division of Coastal Zone Management, 1993f. U.S. Virgin Islands, St. Croix, Southshore Industrial Area APC Comprehensive Analytic Study. USVI Government, St. Thomas, USVI.

Fonseca, M.S., 1987. The management of seagrass systems. *Tropical Coastal Area Management.* August 1987. ICLARM. Metro Manila, Philippines.

Fujita, R.M., M.S. Epstein, T.J. Goreau, and K. Gjerde, 1992. A guide to protecting coral reefs. United Nations Environment Programme. Meeting of experts on the Caribbean Environment Programme. 9-10 November 1992. Kingston, Jamaica.

Gellis, A., 1991. Construction effects on sediment for two basins, Puerto Rico. U.S. Geological Survey. San Juan, Puerto Rico.

Geoscience Associates, 1984a. Phase 1 report; Vulnerability analysis, earthquake hazards of the U.S. Virgin Islands. Prepared for the USVI Government, Office of the Governor, Disaster Programs Office. St. Thomas, USVI.

Geoscience Associates, 1984b. Phase 2 report; Vulnerability analysis, earthquake hazards of the U.S. Virgin Islands. Prepared for the USVI Government, Office of the Governor, Disaster Programs Office. St. Thomas, USVI.

Gjerde, J.D. and R.M. Fujita, 1992. Guidelines for national legislation to protect coral reef ecosystems. Prepared by Greenpeace, Environmental Solutions International, and Environmental Defense Fund. Washington, D.C.

Gladfelter, E.H., 1992. Annotated bibliography of marine research at Buck Island Reef National

Monument, St. Croix, U.S. Virgin Islands. Prepared for the National Park Service.

Gladfelter, E.H., J.C. Bythell, and W.B. Gladfelter, 1991. Ecological studies of Buck Island Reef National Monument, St. Croix, U.S. Virgin Islands: A quantitative assessment of selected components of the coral reef ecosystem and establishment of long term monitoring sites. Part 1. Prepared for the National Park Service.

Gladfelter, E.H., W.B. Gladfelter, D.K. Hubbard, R.C. Carpenter and G.S. Simpson, 1979. Environmental studies of Buck Island Reef National Monument, St. Croix, U.S. Virgin Islands. Part II. National Park Service Report.

Gladfelter, E.H. and W.B Gladfelter, 1980. Environmental studies of Buck Island Reef National Monument, St. Croix, U.S. Virgin Islands. Part III. National Park Service Report.

Gladfelter, W.B., 1982. White-band disease in Acropora palmata: Implications for the structure and growth of shallow reefs. *Bulletin of Marine Science.* 32(2):639-643.

Gladfelter, W.B., E.H. Gladfelter, R.K. Monahan, J.C. Ogden and R.K. Dill, 1977. Environmental studies of Buck Island Reef National Monument, St. Croix, U.S. Virgin Islands. National Park Service Report.

Godschalk, D.R., D.J. Brower, and T. Beatley, 1989. Catastrophic coastal storms; Hazard mitigation and development management. Duke University Press. Durham, NC.

Hubbard, D.K., 1987. A general review of sedimentation as it relates to environmental stress in the Virgin Islands Biosphere Reserve and the Eastern Caribbean in general. Virgin Islands Resource Management Cooperative: Biosphere Reserve Research Report No 20. Virgin Islands National Park.

Hubbard, D.K. (ed.), 1989a. Terrestrial and marine geology of St. Croix, U.S. Virgin Islands. Special Publication Number 8. West Indies Laboratory, Tague Bay. St. Croix, USVI.

Hubbard, D.K., 1989b. Modern carbonate environments of St. Croix and the Caribbean: A General Overview. *In* D.K. Hubbard, ed., Terrestrial and Marine Geology of St. Croix, U.S. Virgin Islands. West Indies Laboratory. St. Croix, USVI.

Hubbard, D.K., 1989c. The shelf-edge reefs of Davis and Cane Bays, Northwestern St. Croix. *In* D.K. Hubbard, ed., Terrestrial and Marine Geology of St. Croix, U.S. Virgin Islands. West Indies Laboratory. St. Croix, USVI.

Hubbard, D.K., 1989d. Depositional environments of Salt River estuary and submarine canyon, St. Croix, USVI. *In* D.K. Hubbard, ed., Terrestrial and Marine Geology of St. Croix, U.S. Virgin Islands. West Indies Laboratory. St. Croix, USVI.

Hubbard, D.K., 1991. Geological development of Buck Island Reef National Monument. Prepared for the National Park Service. Published by West Indies Laboratory. St. Croix, USVI.

Hubbard, D.K., K.M. Parsons, J.C. Bythell and N.D. Walker, 1991. The effects of Hurricane Hugo on the reefs and associated environments of St. Croix, U.S. Virgin Islands: A preliminary assessment. *Journal of Coastal Research.* 8:33-48. Fort Lauderdale, FL.

Hubbard, D.K., J.L. Sadd, A.I. Miller, I.P. Gill, and R.F. Dill, 1981. The production, transportation, and deposition of carbonate sediments on the insular shelf of St. Croix, USVI. Technical Report No. MG-1. West Indies Laboratory. St. Croix, USVI.

Hubbard, D.K. and T.H. Suchanek, 1981. Environmental effects of proposed rock removal at Davis Beach, St. Croix, USVI. Submitted to the V.I. Coastal Zone Management Office. St. Croix, USVI.

Island Resources Foundation, 1977. Marine environments of the Virgin Islands, Technical supplement No. 1. Prepared for the USVI Government, Office, Coastal Zone Management Program. St. Thomas, USVI.

Island Resources Foundation, 1986. Puerto Rico and Virgin Islands coastal barriers summary report. Prepared for the Department of the Interior, U.S. Fish and Wildlife Service. St. Thomas, USVI.

Island Resources Foundation, 1991. Virgin Islands Territorial Park System Planning Project and Hurricane Hugo Coastal Resources Damage and Recovery Assessment. St. Thomas, USVI.

Johannes, R.E., 1975. Pollution and degradation of coral reef communities. *In* Tropical Marine Pollution. E.J. Wood and R.E. Johannes (eds.). Elsevier Oceanography Series, 12. Elsevier Scientific Publishing Company. Amsterdam.

Kenchington, R.A. and B.E.T. Hudson, 1984. Coral reef management handbook. Published by UNESCO Regional Office for Science and Technology for South-east Asia. Jakarta, Indonesia.

Lang, J.C.,H.R. Lasker, E.H. Gladfelter, P. Hallock, W.C. Jaap, F.J. Losada, and R.G. Muller, 1992. Spatial and temporal variability during periods of "recovery" after mass bleaching on Western Atlantic coral reefs. *Amer. Zool.* 32:696-706.

LaPointe, B.E., 1989. Caribbean coral reefs: Are they becoming algal reefs? *Sea Frontiers.* March-April 1989.

Lessios, H.A., D.R. Robertson, and J.D. Cubit, 1984. Spread of *Diadema* mass mortality through the Caribbean. *Science.* 226:335-337.

Loya, Y., 1976. Effects of water turbidity and sedimentation on the community structure of Puerto Rican Corals. *Bulletin of Marine Science.* 26(4):450-466.

Virgin Islands. National Park Service.

Rogers, C.S., 1979. The effects of shading on coral reef structure and function. *J. Exp. Mar. Bio. Ecol.*. 41:269-288. Elsevier/North-Holland Biomedical Press.

Rogers, C.S., 1983. Sublethal and lethal effects of sediments applied to common Caribbean reef corals in the field. *Marine Pollution Bulletin.* 14:378-382.

Rogers, C.S., 1990. Responses of coral reefs and reef organisms to sedimentation. *Marine Ecology Progress Series.* 62:185-202. Inter-Research publications, F.R. Germany.

Rogers, C.S., 1991. Balancing adverse effects of marine-based tourism with marine resource protection in Virgin Islands National Park, St. John, U.S. Virgin Islands. *In* Proceedings of the Regional Symposium on Public and Private Cooperation in National Park Development. August 23-25, 1991. Published by the British Virgin Islands National Park Trust.

Rogers, C.S., 1992. Increased dangers to Caribbean marine ecosystems: Cruise ship anchors and intensified tourism threaten reefs. *BioScience.* 42(5).

Rogers, C.S., 1993 (in press). Coral reef monitoring manual. To be published shortly with support provided from The Nature Conservancy.

Rogers, C.S., L. McLain and E.S. Zullo, 1988. Recreational uses of Marine Resources in The Virgin Islands National Park and Biosphere Reserve: Trends and Consequences, Virgin Islands Resource Management Cooperative: Biosphere Research Report No. 24, Virgin Islands National Park.

Rogers, C.S., T.H. Suchanek and F.A. Pecora, 1982. Effects of hurricanes David and Frederic (1979) on Shallow *Acropora palmata* reef communities, St. Croix, U.S. Virgin Islands. *Bulletin of Marine Science.* 32(2):532-548.

Rogers, C.S. and E.S. Zullo, 1987. Initiation of a long-term monitoring program for coral reefs in the Virgin Islands National Park. Virgin Islands Resource Management Cooperative: Biosphere Reserve Research Report No. 17. Virgin Islands National Park.

Salm, R.V., 1980. Guidelines for the establishment of coral reef reserves. Prepared for WWF/IUCN.

Salm, R.V., 1984. Ecological boundaries for coral-reef reserves: Principles and guidelines. *Environmental Conservation.* 11(3).

Sladen, F.W., 1988. Salt River Bay and environs: A Natural resource summary. Prepared for the V.I. Natural Heritage Trust. St. Croix, USVI.

Small, V., 1982. Sea turtle nesting at Virgin Islands National Park and Buck Island Reef National

Monument, 1980 and 1981. Research/Resources Management Report SER-61. Virgin Islands National Park. St. Thomas, USVI.

Snedaker, S.C. and M.S. Brown, 1981. Water quality and mangrove ecosystem dynamics. U.S. Environmental Protection Agency. EPA-600/S4-81-022, August 1981.

Suchanek, T., 1989. A guide to the identification of the common corals of St. Croix. *In* D.K. Hubbard, ed., Terrestrial and Marine Geology of St. Croix, U.S. Virgin Islands. West Indies Laboratory. St. Croix, USVI.

Tetra Tech, Inc. 1991a. Distinctive habitats of Puerto Rico and the U.S. Virgin Islands: Determination of the type, degree, and sources of environmental stress. Bellevue, WA.

Tetra Tech, Inc., 1991b. Identification of data gaps that hinder the determination of the type, degree, and sources of stress to distinctive habitats in Puerto Rico and the U.S. Virgin Islands. Bellevue, WA.

Tetra Tech, Inc. 1991c. Options to prevent degradation of pristine distinctive habitats in Puerto Rico and the U.S. Virgin Islands. Prepared for the U.S. Environmental Protection Agency. Bellevue, WA.

Teytaud, A.R., 1980a. Preliminary report on potential Significant Natural Area (SNA) sites. Department of Conservation and Cultural Resources. St. Thomas, USVI.

Teytaud, A.R., 1980b. Draft Guidance Plan for the St. Croix Coral Reef System Area of Particular Concern. Department of Conservation and Cultural Affairs. St. Croix, USVI.

Teytaud, A.R., 1987. St. Croix Coral Reef System APC/SNA Report (Draft). Department of Conservation and Cultural Affairs. St. Croix, USVI.

Tobias, W., E. Telemaque, and M. Davis, 1988. Buck Island fish and shellfish populations. Virgin Islands Resource Management Cooperative: Biosphere Reserve Research Report, No 26. Virgin Island National Park.

Tomascik, T. and F. Sander, 1985. Effects of eutrophication on reef-building corals. *Marine Biology*. 87:143-155.

Tudhope, S., 1992. Coral bleaching: Global warming? Report commissioned by Greenpeace International. Washington, D.C.

U.S. Department of Agriculture, 1970. Soil survey Virgin Islands of the United States. Soil Conservation Service. Washington D.C.

U.S. Department of Commerce, 1979. Final environmental impact statement, proposed Coastal Zone Management Program for the Virgin Islands. Prepared by Office of Coastal Zone

Management, National Oceanic and Atmospheric Administration. Washington, D.C.

U.S. Environmental Protection Agency, 1993. Guidance specifying management measures for sources of nonpoint pollution in coastal waters. Report No. 840-B-92-002. USEPA, Office of Water. Washington, D.C.

U.S. Geological Survey, 1984. A workshop on earthquake hazards in the Virgin Islands region. Open-file report 84-762. U.S. Department of the Interior, USGS. Reston, VA.

USVI Government/DPNR, n.d. Public Notice regarding historic resources within submerged lands of the U.S. Virgin Islands. Issued by R.E. Adams, DPNR Commissioner.

USVI Government/DPNR, 1991. Draft report on: An environmental management policy initiative for the East End Area of Particular Concern.

Virgin Island Marine Advisors, 1986. Environmental assessment of proposed dredging in Christiansted Harbor, St. Croix, USVI. Prepared for V.I. Port Authority and Office of Coastal Zone Management. St. Croix, USVI.

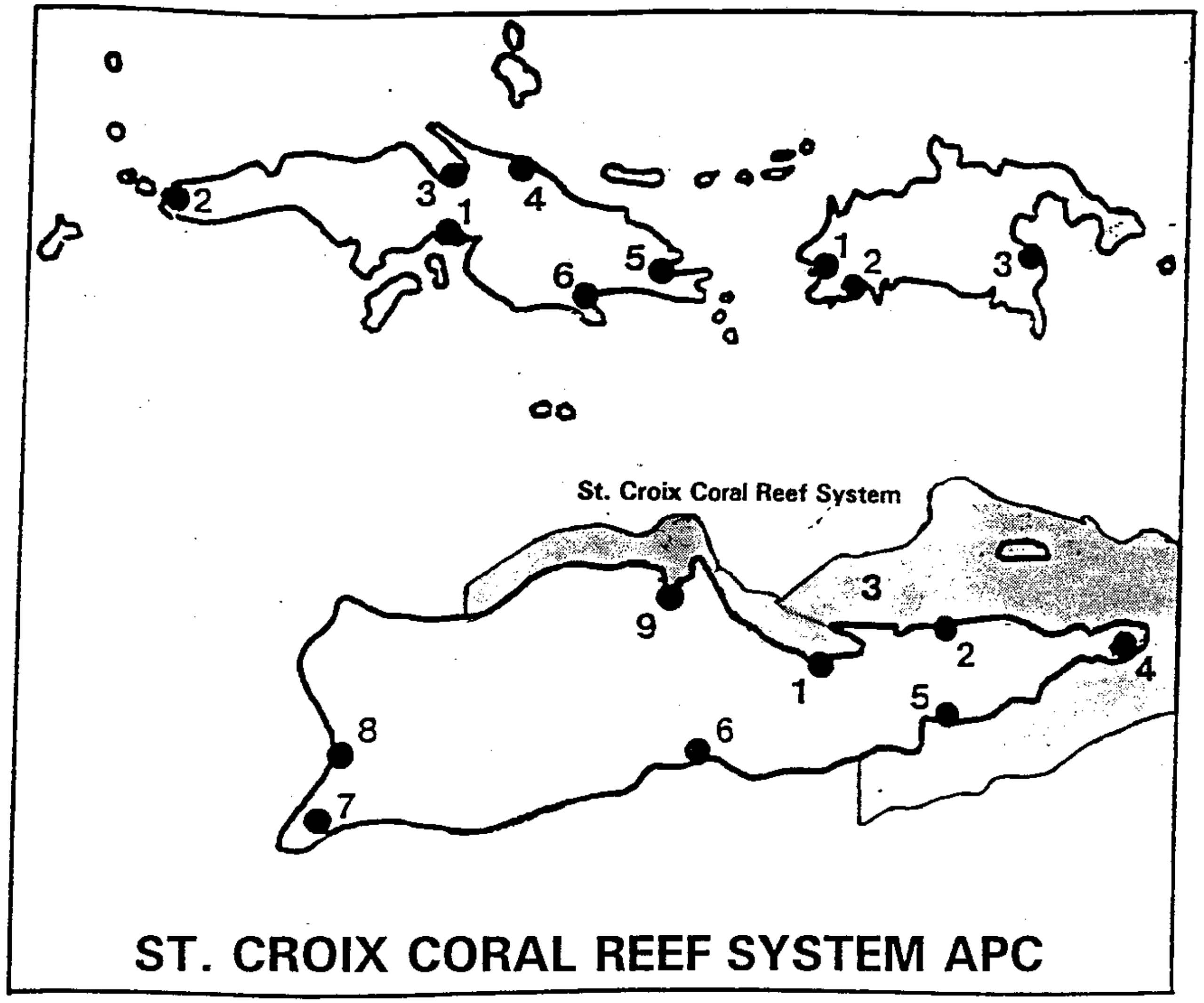
Wells, S.M., 1988. Coral Reefs of the world volume 1: Atlantic and Eastern Pacific. Prepared by IUCN Conservation Monitoring Centre in collaboration with UNEP. Cambridge, U.K.

West Indies Laboratory, 1980. An ecological survey of Cane Bay Reef, St. Croix, U.S. Virgin Islands. West Indies Laboratory, Fairleigh Dickinson University. St. Croix, USVI.

Whetten, J.T., 1974. Field guide to the geology of St. Croix, U.S. Virgin Islands. *In* Multer, G. and L.C. Gerhard, eds.; Geology-Ecology St. Croix, USVI. Special publication no. 5, West Indies Laboratory, Fairleigh Dickinson University. St. Croix, USVI.

Williams, E.H. and L.B. Williams, 1987. Caribbean marine mass mortalities: A problem with a solution. *Oceanus*. 30:4.

Regional APC Map



AREAS OF PARTICULAR CONCERN

St. Thomas

1) St. Thomas Harbor and Waterfront
2) Botany Bay (APR)
3) Magens Bay and Watershed
4) Mandahl Bay (APR)
5) Vessup Bay - East End
6) Mangrove Lagoon - Benner Bay (APR)

St. John

1) Enighed Pond - Cruz Bay
2) Chocolate Hole - Great Cruz Bay (APR)
3) Coral Bay (APR)

St. Croix

1) Christiansted Waterfront
2) Southgate Pond - Chenay Bay (APR)
3) St. Croix Coral Reef System (APR)
4) East End (APR)
5) Great Pond and Great Pond Bay (APR)
6) Southshore Industrial Area
7) Sandy Point
8) Frederiksted Waterfront
9) Salt River Bay and Watershed (APR)

Figure 1
Regional APC Map
Adapted from: USDOC, 1979

ST. CROIX CORAL REEF SYSTEM APC
APC BOUNDARY MAP

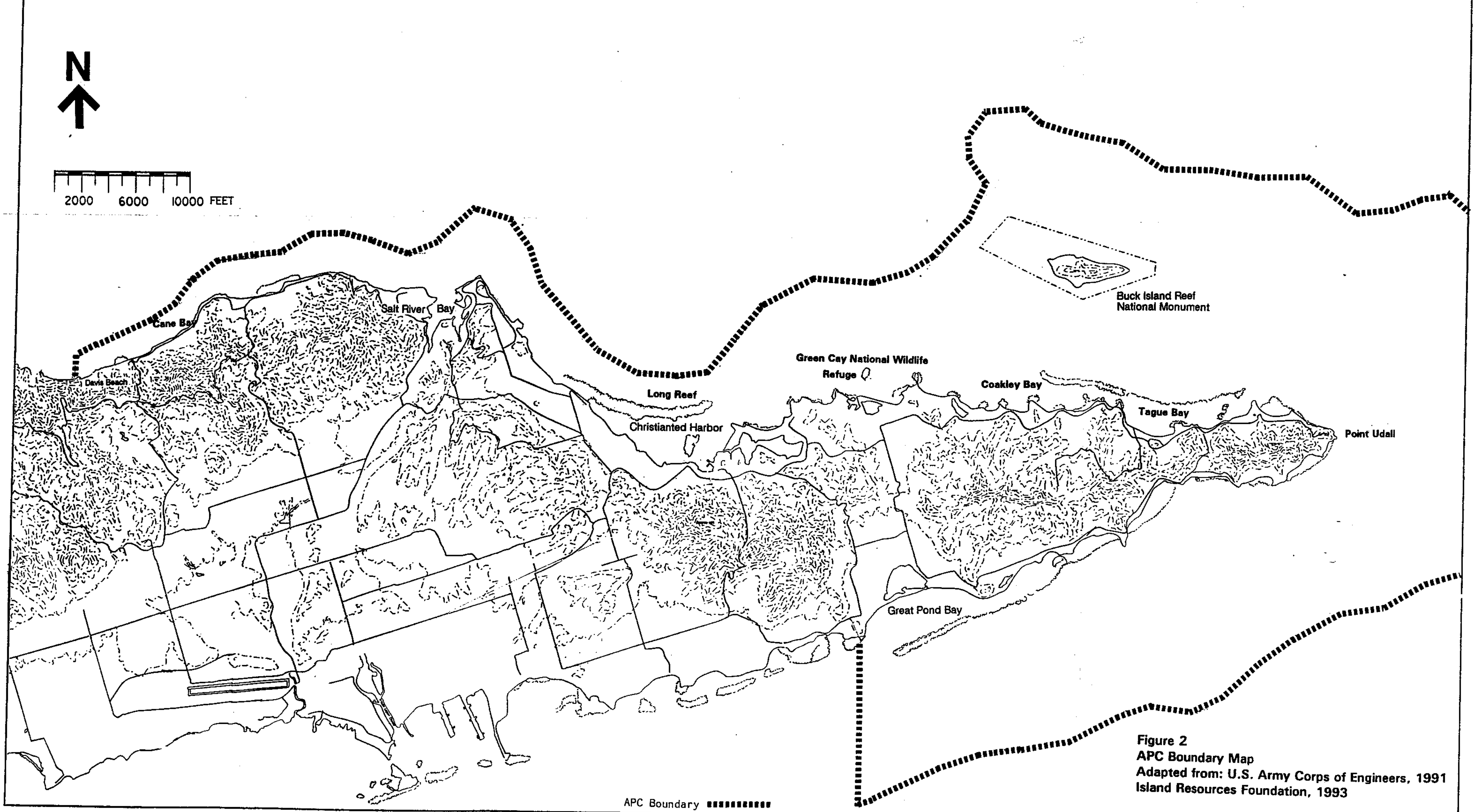


Figure 2
APC Boundary Map
Adapted from: U.S. Army Corps of Engineers, 1991
Island Resources Foundation, 1993

ST. CROIX CORAL REEF SYSTEM APC
BATHYMETRIC MAP

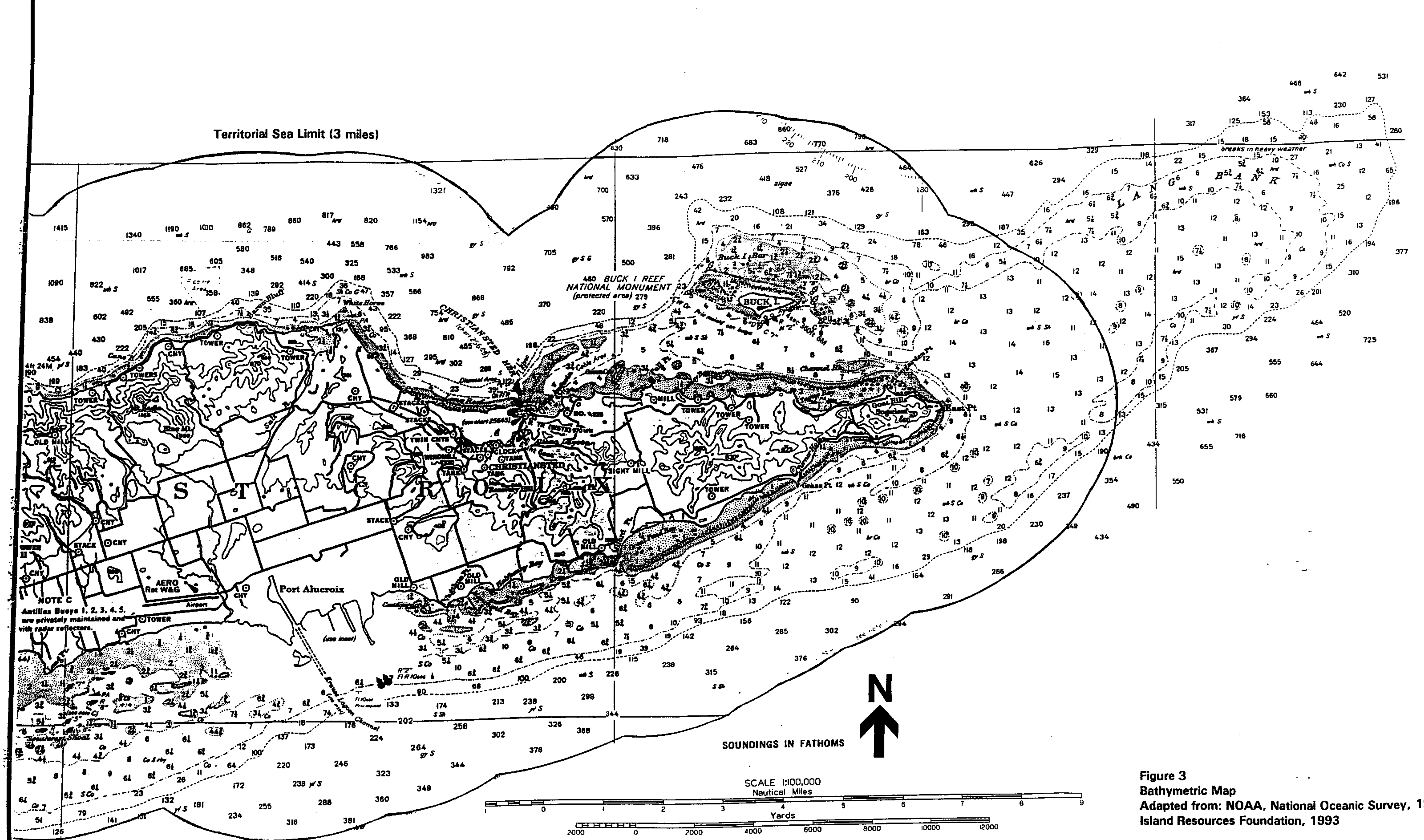
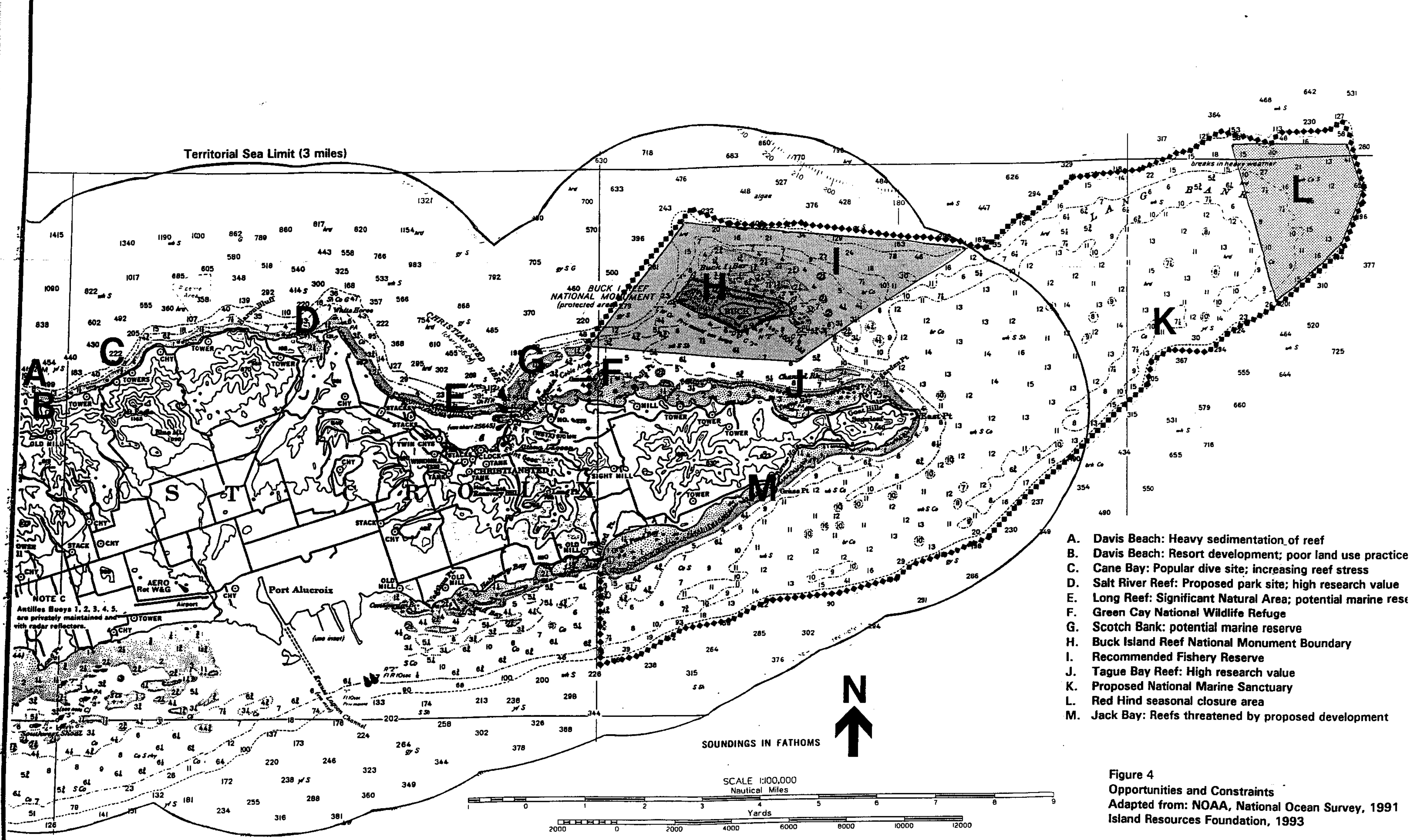


Figure 3
Bathymetric Map
Adapted from: NOAA, National Oceanic Survey, 19
Island Resources Foundation, 1993

OPPORTUNITIES AND CONSTRAINTS MAP



A. Davis Beach: Heavy sedimentation of reef
B. Davis Beach: Resort development; poor land use practice
C. Cane Bay: Popular dive site; increasing reef stress
D. Salt River Reef: Proposed park site; high research value
E. Long Reef: Significant Natural Area; potential marine rese
F. Green Cay National Wildlife Refuge
G. Scotch Bank: potential marine reserve
H. Buck Island Reef National Monument Boundary
I. Recommended Fishery Reserve
J. Tague Bay Reef: High research value
K. Proposed National Marine Sanctuary
L. Red Hind seasonal closure area
M. Jack Bay: Reefs threatened by proposed development

Figure 4
Opportunities and Constraints
Adapted from: NOAA, National Ocean Survey, 1991
Island Resources Foundation, 1993

LEGEND FOR MAJOR DRAINAGE BASINS AND REEF TYPES

Definition of Reef Zones

MIXED CORALS

This zone includes reef flats, patch reefs, and lagoonal fringing reefs. These are most commonly located at a water depth of 0-15 feet. Major species found in this zone include elkhorn corals (Acropora palmata), mound and finger corals (Porites spp.), and head corals (Diploria spp. and Montastrea annularis).

SHALLOW FORE REEF

This zone includes the upper fore reef and reef crest. The water depth in this zone is commonly 0-20 feet but can extend to 40 feet in clear water. This zone is dominated by elkhorn corals (Acropora palmata) with fire corals (Millepora spp.) and coralline algae on the crest. This is the reef zone of most rapid growth.

DEEP REEF

This zone can include the lower fore reef and other deep zones where reef building is taking place. The water depth is usually 20-70 feet but can reach 200 feet at the shelf dropoff. This zone is characterized by head corals (Montastrea spp. and Diploria spp.), platey corals (Mycetophyllia spp. and Agaricia spp.), staghorns (Acropora cervicornis), sponges, and as sea whips and fans (gorgonians).

PAVEMENT

This zone is a level, relatively featureless area of hard bottom. It is usually located at a depth of 40-70 feet, although it can be much shallower in areas exposed to vigorous wave energy. This zone is dominated by sea fans and whips (gorgonians) and has scattered corals. Thin sand patches and channels are common. This is the area of slowest reef growth.

ALGAL RIDGE

This zone is located at, or up to, 3 feet above sea level. It is built by coralline calcareous algae and is often covered by fleshy algae such as Sargassum.

REEF NOTE

The non-reefoid areas are blank. These include sand, mud, and terrigenous rubble.

The reef information shown on these maps can be very useful for sediment reduction and general planning purposes, but it should not be used for navigation or design. The information was adapted from a draft copy of a reef map of the Virgin Islands prepared by W. H. and P. J. Adey of the Smithsonian Institution during 1978.

Reefs are a complex combination of biological organisms. For clarity, five basic reef zones were defined, and the existing reef areas were placed into one of the zones based on their predominant characteristics. The reef zones were identified and plotted by interpretation of recent NOAA aerial photographs on the basis of several years' research carried out in St. Croix. Field verification was not carried out in St. Thomas or St. John. Minor adjustments were made to the original reef map information in order to fit it to the USGS base used for this mapping series.

CULTURAL FEATURES

- Misc. public buildings
- Fire station
- Hospital
- Marina
- Drive-in theater
- School or college, public
- School or college, private
- Apartment complex
- Hotel
- Multistory public housing
- Private buildings
- Golf course

ROADS

- Divided four-lane highway
- Paved
- Unpaved
- Proposed

IMPOUNDMENTS

- Location
- 56A V.I. Dept. of Agriculture Code Number

GENERAL FEATURES

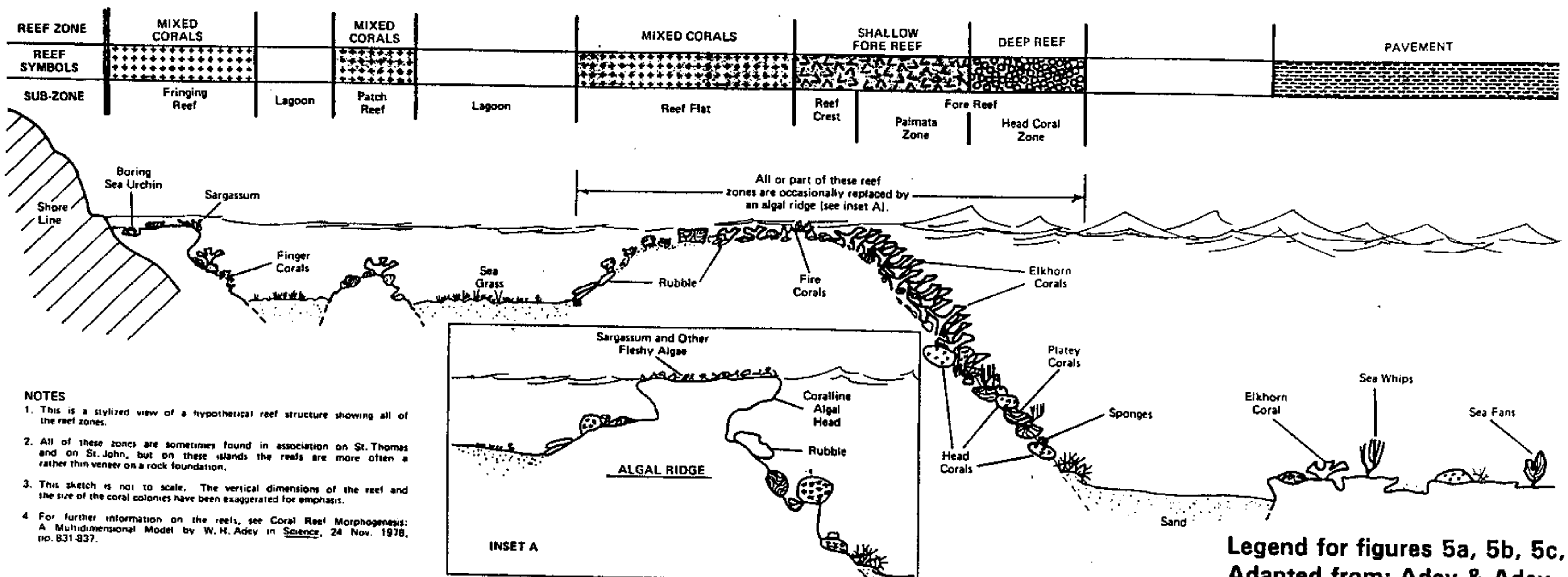
- Index contour (200-ft interval)
- Intermediate contour (40-ft interval)
- Supplementary contour (20-ft interval)
- National park boundary
- Urban limit boundary
- Intermittent stream
- Marsh
- Mangrove
- Proposed development

LETTERING STYLES

MANDAL	Political names
Caneel Hill	Geographic names
Cruz Bay	Hydrographic names
DOBER SCH	Misc. notes and symbol descriptions

DRAINAGE FEATURES

- Significant Drainage Divides
- Boundary of Major Drainage Basins
- 789 acres — Area of Major Basins as Measured to Star



NOTES

1. This is a stylized view of a hypothetical reef structure showing all of the reef zones.
2. All of these zones are sometimes found in association on St. Thomas and on St. John, but on these islands the reefs are more often a rather thin veneer on a rock foundation.
3. This sketch is not to scale. The vertical dimensions of the reef and the size of the coral colonies have been exaggerated for emphasis.
4. For further information on the reefs, see Coral Reef Morphogenesis: A Multidimensional Model by W. H. Adey in Science, 24 Nov. 1978, pp. 831-837.

Legend for figures 5a, 5b, 5c, and 5d
Adapted from: Adey & Adey, 1979
Island Resources Foundation, 1993

MAJOR DRAINAGE BASINS AND REEF TYPES

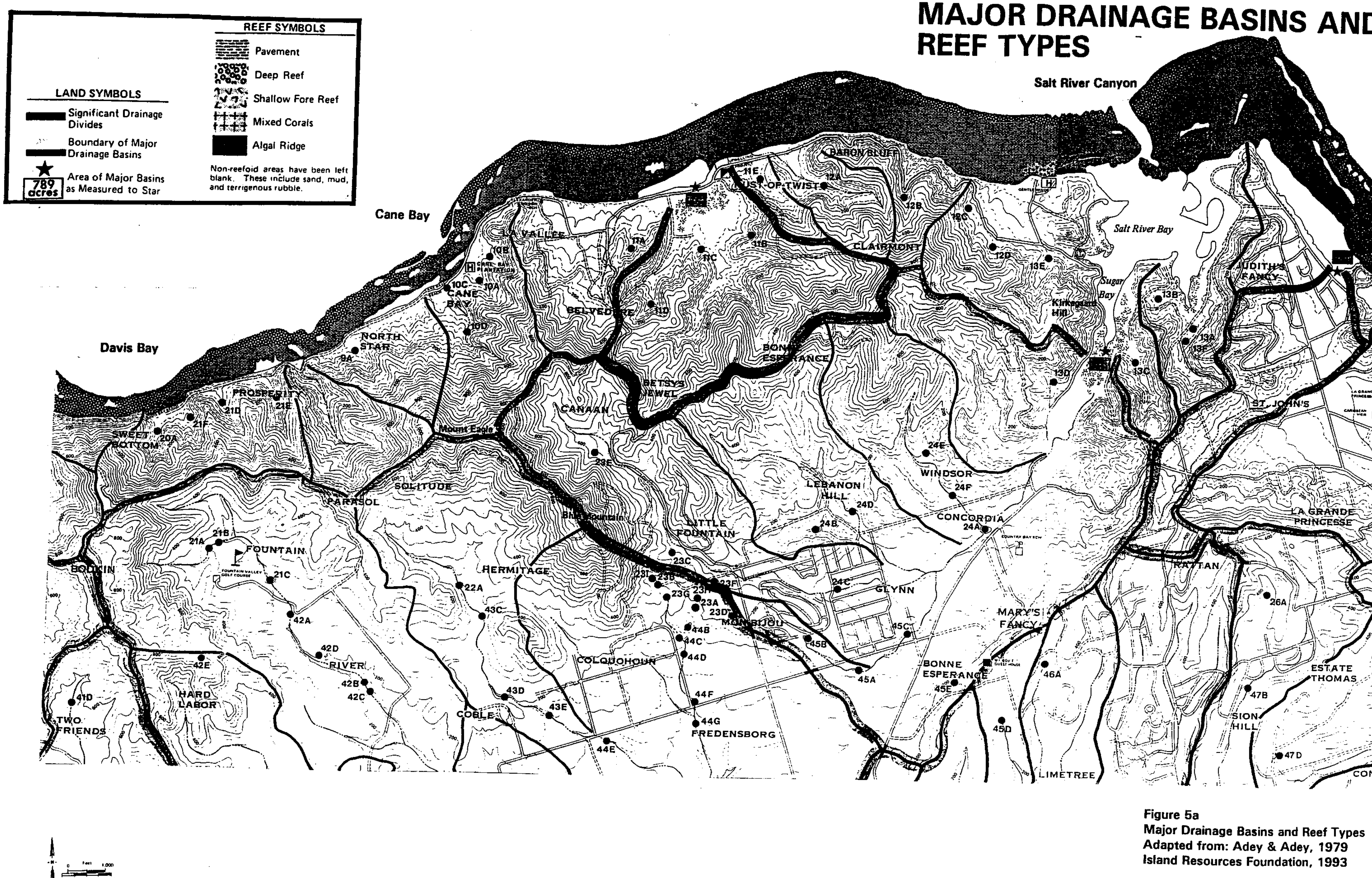


Figure 5a
Major Drainage Basins and Reef Types
Adapted from: Adey & Adey, 1979
Island Resources Foundation, 1993

MAJOR DRAINAGE BASINS AND REEF TYPES

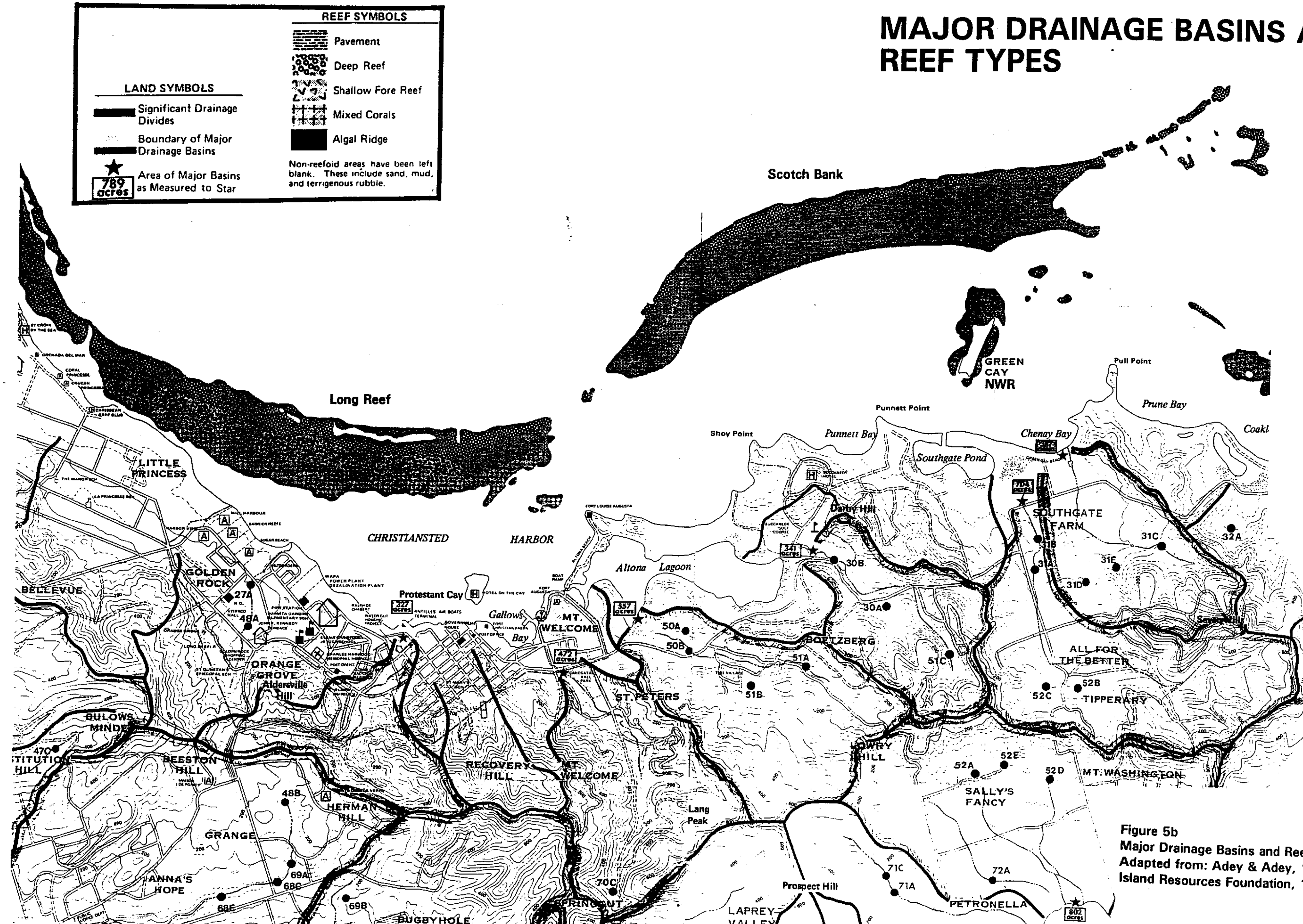


Figure 5b
Major Drainage Basins and Reef Types
Adapted from: Adey & Adey, 1979
Island Resources Foundation, 1993

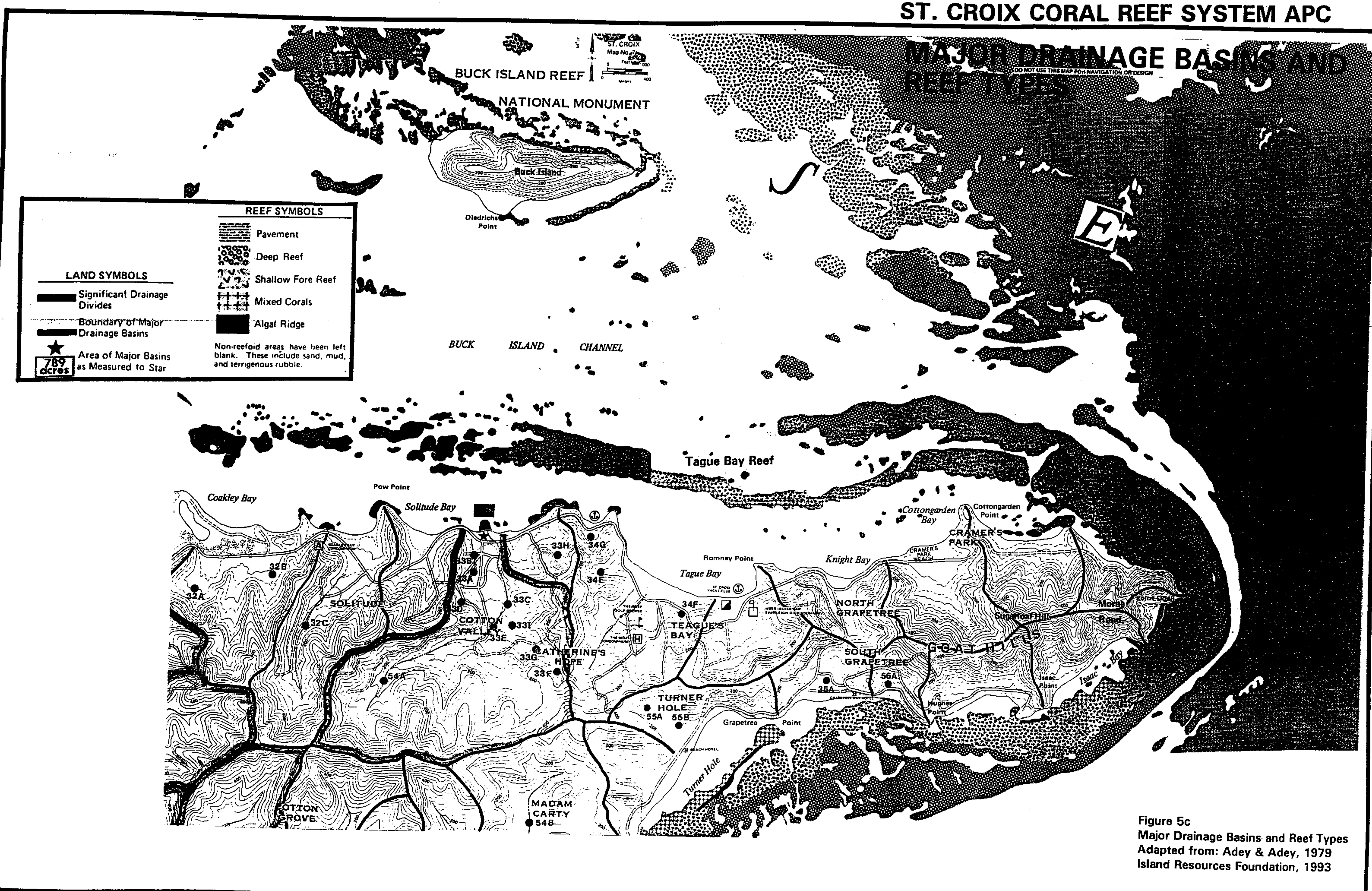


Figure 5c
Major Drainage Basins and Reef Types
Adapted from: Adey & Adey, 1979
Island Resources Foundation, 1993

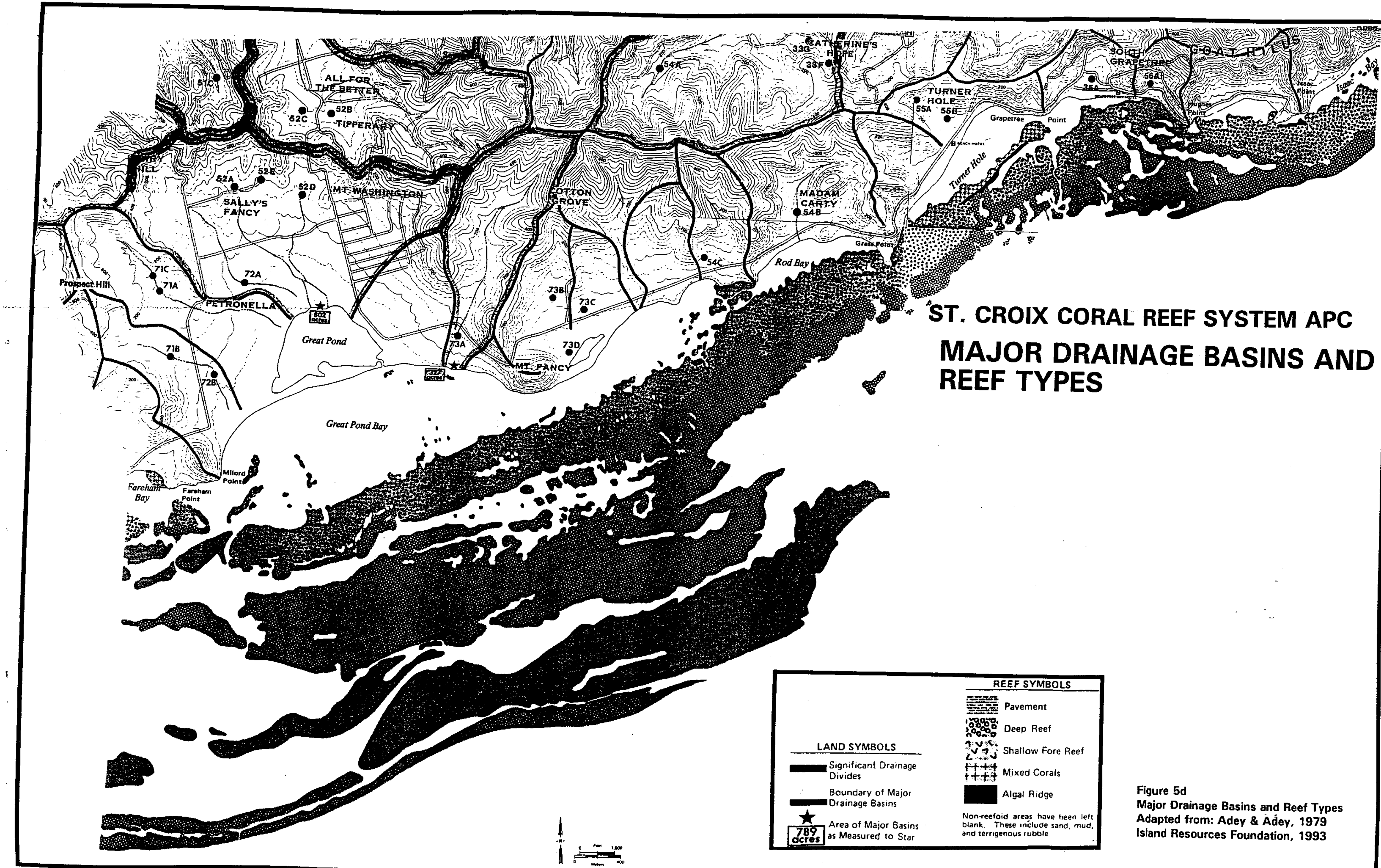


Figure 5d
Major Drainage Basins and Reef Types
Adapted from: Adey & Adey, 1979
Island Resources Foundation, 1993

CORAL REEFS AND AGAL RIDGES OF EAST END

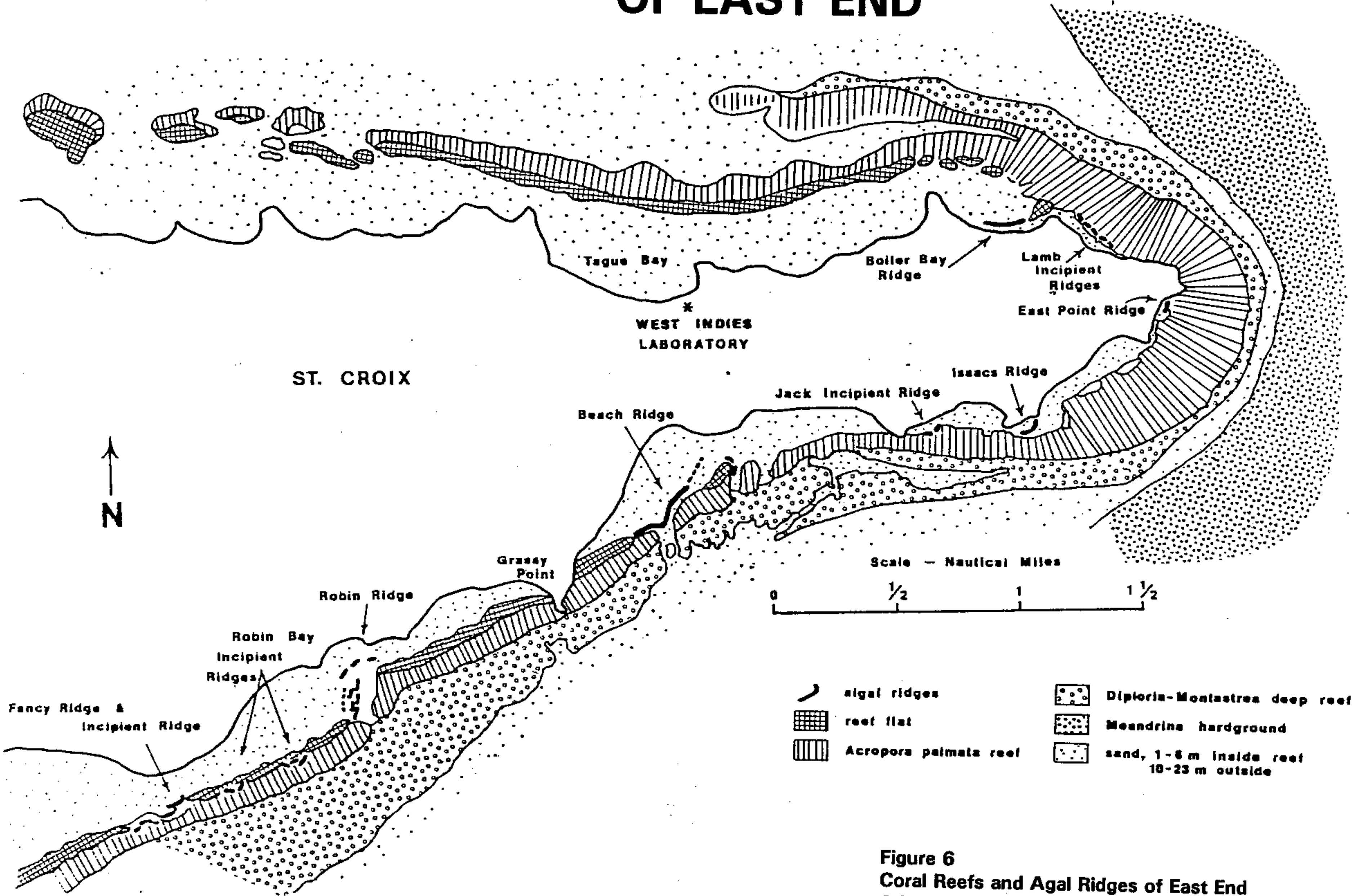


Figure 6
Coral Reefs and Agal Ridges of East End
Adapted from: Adey & Burke, 1976 (After Adey, 1975)
Island Resources Foundation, 1993